UNIVERSITY OF NAIROBI

EVALUATING ANAEROBIC DIGESTION TECHNOLOGY IN REDUCING THE QUANTITY OF SOLID WASTE: A CASE STUDY OF KIGALI DUMPSITE

by

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A thesis submitted in partial fulfillment of the requirements for the award of Masters of Science in Environmental and Biosystems Engineering, Department of Environmental and Biosystems Engineering, School of Engineering.

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DECLARATION

This thesis is my original work and has not been presented to any other University

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DEDICATION

I dedicate this thesis to my family, especially to my sweet, loving husband and my children whose affection, love, encouragement and prayers of day and night made me able to get such success and honor, along with all the hard-working and the respected lecturers

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ABSTRACT

Rwanda is a developing country where the waste generated from households continues to increase due to extensive urbanization and development. Biodegradable organic matter constitutes a great portion of the municipal solid waste from Kigali City. Biodegradable waste is composed of elements that can be degraded by bacteria such as paper, green waste (yard waste), general garbage and other common items containing organic elements like furniture, texture, footwear, as well as high-grade materials. Landfill disposal leads to the production of methane gas as the accumulated waste degrades.

During anaerobic digestion, organic matter is decomposed by microbial aggregates in the absence of oxygen, resulting in the formation of digests and biogas, which consist primarily of methane gas and carbon dioxide. The digest is a decomposing substrate produced by biogas production and can be used as a biofertilizer. The research was focused on the evaluation of anaerobic digestion technology in reducing the quantity of solid waste: a case study of Kigali dumpsite. The research identified the quantity and characteristics of biodegradable municipal solids waste generated in Nyarugenge, the suburban part of Kigali. The survey was conducted every week for four weeks corresponding to a month to estimate the quantity of municipal solids waste discharge per a day. This survey was conducted between 24/June and 20/July. The sorting-and-weighing methodology was used in assessing the waste composition from each of the sample households every week. During the survey, the amount of solid waste generated and dumped in each of the survey areas (villages) was quantified. The total solids waste was found to be 686,000 kg, and the organic solids waste was about 500,000kg. This fraction formed 73% of entire municipal solids waste in Kigali city.

The research analyzed the chemico-physical and biological characteristics of the municipal solids waste. The tests done, Dry matter (DM), Volatile Solids VS, Biological Oxygen demand (BOD) and Chemical Oxygen demand (COD) were 22.4, 910.228gVS/$kg_{DM,}$ 597.714gBOD/kg, and 1328.262g COD/kg_{DM}. The results of laboratory experiments showed that the amount of biogas produced and the maximum cumulative production was about 79 L / kg DM, as the maximum cumulative volume of methane produced was noticed to be about 35.7 L / kg DM. The methane content is about 44% of the total dry biogas obtained. Due to the use of anaerobic digestion settings, biogas tank settings produce lower methane and biogas, but their physicochemical and biological characteristics indicate that this biowaste should produce the required biogas.

The research evaluated the viability of using anaerobic digestion technology. The results from the laboratory tests were used for calculating methane and the potential for electricity generation. The results indicated that the organic waste in Kigali City produces 457L/kg $_{DM}$ of methane. The overall assessed value of methane was 51,384,375 L. The electricity from derived methane was 180,873 KWh. The quantity of municipal waste generated in Kigali City was used for designing the biodigester required. The volume of the biodigester was found to be 58,065m^3. A cost/benefit analysis on the anaerobic digestion technology was done based on the energy recovered, and it revealed that Kigali City will benefit from this project as the population accessing its electricity will be increasing. The electricity from derived methane was 180,873KWh, which is 54% of the daily demand in Kigali.

1 INTRODUCTION

1.1 Background

In many cities of developing countries, the worst environmental and health issues are associated with inadequate solid waste management (SWM). Population growth and urbanization has led to an increase in waste generation in urban areas. The services provided by municipal agencies and private companies have not kept pace with the amount of waste generated. Several problems are due to the disposal of organic waste into still-used open dumps. Waste, mainly organic waste, is dumped in open areas, causing serious environmental pollution to soil, surface water and groundwater (Merseyside and Halton, 2011).

The expanded problem related to the collection and dumping of household and industrial waste has been combined to create a complex and difficult stage where this service has been known so far (Phale, 2005).

Organic waste accounts for 20% to 80% of total municipal solid waste (MSW), depending on the level of economic development in each country. The EU produces about 25 to 35 million tons of biodegradable waste per year, nearly 50% of which include green waste in public places and parks and garden waste from households (Adhikari *et al.*, 2010).

Solid waste generation is an inevitable result of resource use and economic development. Disposing of such waste is a major environmental concern. In Rwanda, Ministry of Infrastructure (MININFRA) wishes to establish solids waste management landfills in Karongi and Rusizi in the framework of Urban Development Program (2008-2012) to allow improved quality of life, public health, and environmental conditions for the urban populations in Rusizi and Karongi. But MININFRA recognized that this project could have adverse environmental impact on disease transmission, groundwater and surface water pollution, greenhouse gas emissions and general air pollution as well as ecosystems damage, among other negative effects.

Biodegradable waste includes organic matter, which can be decomposed by bacteria such as paper and cards, green waste (i.e. garden waste), food waste, debris with organic elements (furniture, texture, footwear), and fine materials. When the waste is degraded in landfills, the process results in methane gas production. Methane is a greenhouse gas, 20 times more effective than carbon dioxide. Emissions from manufacturers using raw materials or coal and natural gas to produce energy can be avoided by saving more carbon. As a result, legislation implementing EU landfill directives has gradually limited the amount of biodegradable municipal landfills to 35% by 1995 before 2019/20 (Veeken, Hamminga and Mingshu, 2005).

A large amount of paper, green and cards waste are recycled or composted, but usually, other biodegradable materials, including food waste, remain in the residual waste stream. There are many options for collecting energy/soil quality-enhancing products (organic fertilizers) from biodegradable parts of municipal solid waste (Veeken, Hamminga and Mingshu, 2005).

Anaerobic digestion is the controlled decomposition of organic matter in the absence of oxygen. It is a controlled process of microbial decomposition. Under anaerobic conditions, microbial populations convert biodegradable organic material into methane, carbon dioxide, humus, and inorganic nutrients (Chynoweth D.P, 1996). The biodegradable organic fraction of MSW includes food remains, yard trimmings, and paper. This kind of waste is rich in lignocellulose, proteins, lipids, and starch. Lignocellulose is a generic name for cellulose, hemicellulose, and lignin, which are the three main components of plant tissue. About (40-50) % of lignocellulose is cellulose. The option of treating the biodegradable organic waste part of the municipal waste using an anaerobic digestion technology will have enormous economic benefits to the country as a whole as it will contribute to the production of electrical energy through biogas. It will also contribute to the conservation of soil in the agricultural regions in Rwanda by using the digester slurry as a soil enhancing material (manure). Overall, there are many other benefits associated with the reduction of solid waste destined for the landfill/open dumpsite. These include: -

- Providing more jobs for workers with lower qualifications and higher qualifications.
- Recovering costs associated with transportation and tips.
- Saving on waste management costs due to lower final disposal levels, resources augmentation and higher resource use efficiency.
- Reduction of greenhouse gas (methane) emissions.
- Improvement of air quality.
- Enhancing the use of green energy from biogas-based electricity generation.

In the survey made in Rwanda by (Mbuligwe, 2013), he determined that the political environment was quite supportive and conducive to good solid waste management (SWM), although the highest administrative and political levels were given high priority. SWM lacks data for all surveyed areas, solids generation and composition data are not of good quality, and there are no plans to improve this. In addition, SWM shares resources with other services, which are often more important than

SWM. Although a certain degree of cost recovery has been implemented, full cost recovery has not yet been achieved in the three towns surveyed. For the surveyed area, the disposal site is still a big problem because it is not suitable, and the disposal site used in the future does not meet the standards of the appropriate solid waste final disposal site. Based on existing population data for similar towns and solid waste generation data, the total solid waste production in Nyanza town is estimated at 19,200 kg/day, and 15,000 kg/day and 9,600 kg/day for the town of Nyagatare and Kayonza respectively.

Organic waste management in rural areas is performed by composting and mixing in fields and other types of waste can be reused or buried. In urban areas including Kigali City, solids waste are collected and disposed of in open dumpsites or landfills. In some areas, solid waste is collected by some cooperatives, and the organic waste is sorted and recycled into compost and briquettes. This helps to reduce the amount of waste in the environment significantly. Although the solids waste collection has been improved significantly, waste separation at the source is still low and inadequate in general. In Kigali City, disposal of solid waste poses serious risks to safety and health. Solid waste is disposed of into open dump sites with simple management techniques that are likely to cause both environmental and health effects (Rwandan, 2018).

To find solutions to these challenges, the Rwanda Environment Management Authority (REMA) has devised plans to ensure suitable solid waste management in collaboration with other stakeholders at the district level (Rwandan, 2018).

1.2 Problem statement

Solid waste management is an important issue worldwide. In 2006, the municipal solid waste total amount generated attained 2.02 billion tons as estimation, an annual increase is about 7% since 2003 (Note, 2007). From 2007 to 2011, the global generation of urban solid waste was estimated to grow by 37.3%, equivalent to roughly 8% increase per year (Note, 2007). In Kigali, the municipal solid waste generated was being taken to the dumpsite at Nyanza Kicukiro. In 2011, the dumpsite became full, and a new site was identified in Nduba area, in the eastern suburbs of Kigali City.

It is foreseen that even this new dumpsite will also become full and unable to handle more municipal solid waste. A solution is therefore required to reduce the amount of municipal solid waste destined to the dumpsite so that Kigali City will avoid the spreading of solid waste dumpsites all over its suburbs. An alternative technology for handling municipal solid waste such as anaerobic digestion with the purpose of producing biogas for energy generation and compost as a soil conditioner would be more sustainable, as it would reduce the amount of biodegradable fraction of municipal solid waste destined for the dumpsite in Kigali City.

This would also reduce the pollution burden on underground water as well as surface water from the leachate generated by decaying/rotting organic waste. The added benefit of recovering energy and compost as a soil conditioner enhances the attractiveness of the anaerobic digestion technology.

Electricity is an important driving force for modern technology and socio-economics in that it is used in cooking, lighting, charging phones and industrial processing. This represents currently only 4% of primary energy consumed in Rwanda. However, it is planned to grow exponentially over coming years. The population access the electricity is 19%, but there are plans to increase the accessibility up to70% (Ministry of Infrastructure, 2014).

Access to electricity in Rwanda remains low, particularly in rural areas. Even if the plan is implemented, by 2020, 40% of the population will stay without electricity. However, the rate of electricity increased from 6% in 2008 to 35.3% in May 2017. Additional effort is needed to supply electricity to those people who will be keeping away from the domestic network (Dennis Matanda and Rwandan Ministry of Infrastructure, 2017).

According to the EWSA report: “Although the electricity access level in Rwanda is still low compared with Africa’s and sub-Saharan Africa’s average access rates of 40% and 31% respectively, the country’s electricity access rate has more than tripled from 5% in 2005 to the current access rate of 18%. To achieve the above access rate target above by 2018, Rwanda will explore both on-grid and off-grid solutions ranging from solar home systems to small off-grid hydro installations.” (Rwanda, 2015)

However, the development of power projects in recent years has increased power supply from 2% in 2000 to 16% in January 2013. The continued expansion of the grid by 2018 is expected to come from hydropower (168.68 MW), solar (20 MW), methane (253.6 MW) and peat (210 MW). (Rwanda, 2015)

This means that in Rwanda, there is a gap in electrical energy, and the problem of energy is aggravated by the lack of ability to implement new technology. Nonetheless, the management of biodegradable fraction of solids waste generated from Kigali City or elsewhere in Rwanda will be handling or reducing electricity energy gap through the production of biogas and conversion of the same to electricity through biogas engines.

1.3 Objective

1.3.1 Broad Objective

To evaluate the potential of anaerobic digestion technology in reducing the quantity of solid waste destined to the dumpsite in Kigali.

1.3.2 Specific Objectives

(i) To identify the quantity of Mixed Solids Waste stream generated in Nyarugenge suburban part of Kigali, which is disposed at Nduba dumpsite.

(ii) To estimate the amount and characteristics of the biodegradable fraction of mixed solid waste stream destined to Nduba dumpsite in Kigali.

(iii) To evaluate the viability of using anaerobic digestion technology to recover green energy.

(iv) To carry out cost/benefit analysis on the anaerobic digestion technology as an alternative to dumpsite disposal of the biodegradable fraction of the mixed solid waste from Kigali City.

1.4 Hypothesis

Biodegradable organic matter constitutes a great portion of municipal solid waste from Kigali City. This fraction of municipal solid waste can be gathered and used as raw material for an industrial size anaerobic digester for the production of biogas for generating green electricity and compost as the end products. Moreover, the amounts of municipal solid waste destined for the dumpsite can be reduced by a huge fraction and consequently, lengthen the duration of usage of Nubba dumpsite while contributing to the economy of Kigali and the greater Rwanda economy.

1.5 Justification

Rwanda is a developing country where the waste generated from households continues to increase due to the extensive urbanization and development. The waste materials are not good as they have significant effects on aesthetics, health, and the environment. The implementation of a different approach is still a problem in Rwanda as a developing country due to lack of knowledge, ignorance, poverty, etc.

At the moment, there are few enterprises/individuals that are using the anaerobic digestion technology to convert the biodegradable fraction of municipal solid waste to biogas and compost.

However, this is also on a small scale and cannot handle all biodegradable waste generated in the City of Kigali. This research seeks to establish the viability of using anaerobic digestion of the biodegradable fraction of organic waste on a large scale to produce biogas for electricity generation and compost for soil enhancement and in effect, reduce municipal solid waste generated from Kigali City ending up at Nubba dumpsite.

1.6 Scope of study

The research studies the viability of using anaerobic digestion technology in reducing the quantity of municipal solid waste disposed of in Kigali City dumpsites and revising the waste management situations, by estimating the quantity of municipal solid waste generated daily, monthly, and yearly and providing information on technologies available for diverting biodegradable waste away from landfills. There will be an investigation on quality and market issues in relation to the end-products (biogas and compost) and design of a digester for the transformation of the biodegradable organic waste into biogas and compost.

The waste generated throughout the country is not in the same quantities. It varies from one industry to another or one region of the country to another. In Kigali City, the urban areas are economically developed, and they are areas of high population and numerous households which generate a higher quantity of municipal waste. Only when these are confronted by the problem of disposal, management and accumulation will results be experienced. Therefore, my research will cover the municipal solids waste generated in Kigali City.

2 LITERATURE REVIEW

2.1 Background

Three-quarters of municipal solid waste generated by households and businesses is biodegradable waste, including (organic) or natural materials. Through natural processes, these materials decompose (biodegrade) over time. The process focuses primarily on biodegradable municipal waste (BMW), which is produced primarily by households and businesses. In addition, the main biodegradable component of municipal waste is garden junk, food, waste cardboard, and paper. (Roche Dick, 2006)

Figure 1: Typical biodegradable materials: the majority proportion of the waste streams we produce is biodegradable waste

Table 1: The sources, proportion, and main components of the biodegradable total waste stream (Department of the environment & heritage service, 2003)

Waste Stream[1]	Sources	Biodegradable Proportion of Total Wastes[2]	Biodegradable Components
Municipal Waste	Household and Commercial Premises	71%[d]	Kitchen waste (kitchen) Paper and paperboard Green waste (garden)
Commercial and Industrial Wastes	Commercial and Industrial Premises	Commercial: 80%[b] Industrial: 50%[b]	Waste food processing. Edible oil and fat Kitchen waste (kitchen) Paper and paperboard Wood Textiles
Packaging Wastes	Home, Commercial and Industrial waste	53%[c]	Paper and paperboard Wood
Construction and Demolition Wastes	New construction Building Demolition works	1%[d]	Wood
Sewage Sludge	Waste Water Treatment Works	100%	Sewage sludge
Agricultural Wastes	Agricultural, horticultural and local partner	99%[d]	Manure and sludge Straw and vegetables waste Paper and paperboard Fallen Cattle

Notes:

[1]. For definitions, see the Glossary of Terms

[2]. Estimated biodegradable ratios based on data from:

[a]: NI 2000 Waste Characterization Study

[b]: The National Waste Strategy for Wales

[c]: Packaging Waste Chapter, NI Waste Management Plans

[d]: EHS and DARD Waste Surveys

The degradation of waste disposed in landfills gives rise to the production of methane gas. Methane is 20 times more potent as a greenhouse gas than Carbon Dioxide (CO_2). In the world, the country that produces the largest amount of municipal solid waste (MSW) is the United States, with 387 million tons (2010). About 8% of this is for Waste to Energy (WtE) facilities, mainly mobile grate technology. With a population of more than 300 million, the amount of waste generated per capita is reduced to 1,2 tons per year. In general, the higher the GDP of a country, the higher the generation of municipal solid waste. However, when comparing the amount of waste generated per capita with other developed countries, it is clear that Americans produce more waste. On average, about 8% of municipal solid waste is used to convert waste into energy, and about 25% is used for recycling or composting. The remaining (63%) ends up in landfills (Themelis and Mussche, 2013).

China is one of the fastest-growing countries in the world, so waste management issues are getting worse. Due to the low calorific value (LHV) of municipal solid waste, China is committed to developing new technology, more specifically a circulating fluidized bed that is particularly suitable for its waste. Since 17% of MSWs are handled in waste to energy (WtE) facilities, it is clear that China's work is better than the US, but they still have a long way to go. In addition, most of the waste is still being landfilled (Themelis and Mussche, 2013).

Japan's sustainable waste management level is higher than that of the United States and China. It produces about 65 million tons per year, of which 40 million tons are heat-treated. The rest is recycled and/or composted, and only 2% is landfilled. In addition, due to strict government regulations and very limited land availability, new technologies that appear to be economically viable in other parts of the world have been built. Japan can be seen as a leader in the development and implementation of traditional and new heat treatment technologies. (Themelis and Mussche, 2013).

A 2012 World Bank report estimated that by 2025, more than 40% of the world's municipal solid waste will be produced in East Asia and the Pacific (Yearbook, 2012). In China, urban cities have collected more than 180 million tons of waste, domestic garbage. According to (L. Jianxin, Y. Jian-hua, C. Yong, Yan Mi, 2003), similar to most low- and middle-income countries, the general practice of municipal solid waste disposal in China is through the landfill, whether in sanitary landfills or open dumping site.

In recent years, Europe has made substantial progress in transferring waste from landfills, both in absolute quantities and in the total amount of waste generated. Despite a 7% increase in sectoral economic output, the absolute value of waste in the EU 28 and Norway fell by 25% between 2004 and 2010. Although the sectorial economic output increased by 13%, the waste generated by the service industry decreased by 23% during the same period (Jock *et al.*, 2015).

During the same period, the EU 28 countries, Iceland and Norway reduced the total waste (excluding minerals, burning, animal and vegetable waste) from landfills by 23%, from 25 billion tons to 157 billion tons. Part of the reduction in landfills is due to increased waste recovery and incineration. In the EU-wide target, recovery rates are often the fastest in waste streams (European Environment Agency, 2009). When it comes to consumption, despite real household spending increasing by 7%, the total amount of municipal waste generated by EEA countries fell by 2% between 2004 and 2012. In the same period, per capita, urban waste production fell by 5%, and per capita waste generation fell from 503 to 478 kg.

In Africa, waste generation and management are different due to various factors such as the level economic development, the standard of living, availability of funding, political stability, willingness, and waste management regulations. Generally, African countries generate low rates of MSW, with the exception of Comoros and Seychelles where the generation rate exceeds 2kg/capita/day (Chandrappa and Das, 2012). The main reason for these countries to produce a high rate of MSW is that these two Africans countries are an island, and the huge amount of waste generated is associated with the tourism industry.

The Department of Environmental Affairs and Tourism (Rossouw *et al.*, 2000) developed integrated pollution and waste management policy, and South Africa noted that the impact of waste is a major challenge in the twenty-first century. According to the 1999 South African Environmental Report ('Department of Environmental Affairs and Tourism Department of Environmental', 2000), more than 42 million cubic meters of solid waste is produced each year. Due to population growth, urbanization, and economic growth, the amount of waste generated has increased.

In sub-Saharan Africa, more than 50% of the population will live in cities in 2020. This will increase the productivity of daily production waste by as much as 1.0 kg (Ahmed, S.A. and Ali, 2004). For example, in Zimbabwe, the United Nations Environment Programme (UNEP) Africa Environment Outlook (AEO) estimates that average per capita solid waste production is 0.7 kg/day, compared with 1.0 kg/day in Tanzania (Sector, 2012). A large proportion of most waste is organic. In Mauritius, mixed municipal solid waste has increased substantially from 0.8 kg per capita, with a daily per capita output of about 1.1 kg (Surroop, D. and Mohee, 2011).

In Kenya, there are no national statistics on the level of waste generation. However, per capita, urban waste generation in urban areas of Kenya is estimated to be between 0.29 and 0.66 kg/day (NEMA, 2005). The amount of medical waste generated is about 909,182 tons/year, and the infected waste accounts for 75%. For other categories of waste, no national data was found. For urban waste, data was found for four towns: Nairobi produced approximately 2,400 tons of waste per day while Nakuru, Kisumu, and Mombasa produced 700 tons, 900 tons and 1,500 tons respectively (Starovoytova, 2018). About 61% of this urban waste comes from residential areas, 21% from industrial activities, and the rest from hospitals, markets and other sources (Starovoytova, 2018). Due to changes in production and consumption patterns, urbanization, industrial and service activities, the complexity of waste generated is increasing (United Nations, 2009).

(Sarraf, 2002) estimates that the total cost of environmental degradation in Egypt is between 1 billion and 1.9 billion Egyptian pounds per year, equivalent to 3.2-6.4% of GDP. However, the cost of environmental damage caused by solid waste is estimated at 0.2% of GDP. According to a 2007 survey, the amount of solid waste produced in Egypt each year is between 600,000 and 700,000 tons/year (United Nations, 2009).

In Rwanda, since 2005, improvements have been made in the management of solid waste, and municipal regulations have been implemented to prohibit the dumping of domestic waste outside of the private property. Although solid waste collection has improved significantly, there is a health risk for garbage collectors (mainly women). Poor handling of solid waste poses serious safety and health risks, especially groundwater contamination (REMA, 2010).

The collected waste is transported directly to the landfill. In some areas, waste is transferred to the transfer station, where organic waste is sorted and recycled into compost and briquettes. In other areas, most of the organic waste is removed from the collection point and used to generate biogas, greatly reducing the amount of waste surroundings. Despite efforts to recycle, Rwanda's waste recovery rate remains relatively low. In addition, the City of Kigali produces approximately 450 tons of solid waste, of which the biggest proportion of organic waste comes from households, restaurants, hotels, and markets (REMA, 2010).

2.2 Policy And Legislative Context

2.2.1 Introduction

There are a number of laws and regulations that address the state of the country and they involve:

a. Public cleaning, regulating the collection and disposal of solid waste from houses, public places, commercial and industrial sites.

b. Transportation of household and industrial waste, composting, incineration and land disposal.

The gap between waste management policies and legislation and actual waste management practices is widening due to continued capacity constraints or the absence of waste management facilities for different waste streams. Addressing this capacity gap requires significant investment and technical knowledge. The means of accessing these are far-fetched (Mwesigye *et al.*, 2009).

Further, policy planning, waste planning, and management are significantly influenced by a range of waste management strategies ranging from national to local levels (Devon, 2010). In general, such strategies set in place the principles for the way waste should be managed. Nonetheless, they do not fully address the special element of where the provision for the waste management facilities should be located. Furthermore, the quantity is not fully considered by these strategies as well as wide distribution, phasing or capacity of such facilities and their associated infrastructure at the local level. This is to be addressed within the Kigali waste plan.

Table 2: The relationship between planning policy and the various waste management strategies

International: Kyoto Protocol United Nations Framework Convention on Climate Change
European Waste Directives: Waste Framework Directive Landfill Directive Waste Incineration Directive
National: PPS 10: Sustainable Waste Management

Further, waste planning and waste management are heavily influenced by EU legislation. This can be attributed to the potentially significant environmental impact that waste management can have. Therefore, at an international level, European Directives are targeting sectors involved in the manufacture of vehicles, electronic equipment, and packaging to ensure waste is managed in an appropriate manner.

As shown in the figure above, an international connection of policy above European legislation also exists. International legislation and agreements regarding environmental protection have a role in regulating waste management. The Kyoto Protocol and the United Nations Framework Convention on Climate Change are arguably the two most well-known international policy drivers of reducing the effects of climate change. The Kyoto Protocol is particularly pertinent as it sets down international legally-binding targets for reducing global greenhouse gas emissions. This is relevant to waste planning as waste management processes can generate a variety of these gases. For example, landfill generates methane, a particularly powerful greenhouse gas. A high-profile agreement, relating particularly to waste, is the Basel Convention which regulates the international movement of hazardous waste. Together, these international agreements inform European and national waste management and planning policy (Devon, 2010).

2.3 Policy and planning

Integrated policies and strategies for waste management and hazardous waste (integrated waste management) comprise the waste collection, waste disposal sites, waste recycling, etc. These should address the recycling of paper, plastic, lubricants, batteries, and e-waste. Integrated waste management plans must support poverty alleviation with waste management as a source of employment to generate income. It is important to consider the economics of these operations: logistics, waste pretreatment (load purification) and after-treatment (high-quality digest). The development of Anaerobic Digestion (AD) facilities (all types) requires domestic policies to develop appropriate economic mechanisms. This mainly involves the possibility of selling by-products of the facility: electricity, heat, digestives and composting. While the key factor affecting the availability of each waste treatment process is the entrance fee, other factors also have a significant impact on the economic viability of Anaerobic Digestion (AD) plants (Rolewicz-Kalińska *et al.*, 2016).

2.3.1 Legal aspect including enforcement

There is a need for strict enforcement. It is required to gradually provide ongoing review and update legislation, adapting it and enabling it to implement important response mechanisms to address new developments and future challenges such as e-waste, and to adopt the principle of expanding producer responsibility as it is practiced in several industrialized countries.

2.3.2 Policy and legislation context in Kigali

Kigali's speech and span have been the result of some deliberate efforts by policymakers, implemented by technicians who manage urban affairs, and fully embraced and owned by Kigali citizens.

Today, Kigali is one of the cleanest cities in Africa. Through feedback from residents themselves and visitors, there is clear evidence that there is a clear understanding of this effort (Times Reporter, 2012). Kigali City has received support from the government and residents themselves to keep it clean.

Kigali has private companies that collect household waste from public places in each region and get a monthly payment. Living in a social and clean environment is the constitutional right of all citizens under Article 49 of the Constitution. It states in this section that "Every citizen of the country has the right to live in a safe and clean environment". Article 3 of the Organic Law on the Environment N004 / 2005 of 08/04/2005 states: "Everyone has a responsibility to protect and promote the environment. The State has the responsibility to protect, promote the environment"

This is why the Rwandan Environmental Authority (REMA) public agency decided to promote the implementation of the national environmental policy and maintain the city's green and clean subsequent legislation. Working with the City of Kigali officials and the Rwandan National Police, REMA handles inspections to control how residents comply with the implementation plans and regulations. It has been the training of community policing committees, including providing them with minimal knowledge of environmental crimes within the community. If any intervention is required, trained personnel can be called. "All of this is achieved through community work" (Times Reporter, 2012).

A summary of the geographical features of the Nduba dump site used in the City of Kigali, where the project is located, is shown in the following table:

Table 3: Geographical characteristics of Nduba dumpsite (Bakhresa Grain Milling Rwanda, 2019)

Sr No.	Parameters	Details
1	Latitude	$1^0$37'S
2	Longitude	$30^0$56'
3	Elevation ASL	1499.8m – 1523.2m
4	Weather conditions: -Annual Average Maximum Temp. -An Average Half Min. Temp. -Annual Total Precipitation Predominant wind direction	 16°C 29°C 910-1120mm, N-S
5	Land use at the project site	Used to be occupied land, mainly for subsistence agriculture
6	Nearest Highway	By the Road Kimironko-Rwamagana
7	Nearest Human settlements (Village/Town)	Kimironko Residential area, approximately 3km
8	Forest Reserve within 10km radius	None
9	Ecologically sensitive zones (Protected Areas/Wetlands…)	Slope meets a small valley at the bottom of the hill, the beginning of which is part of the project site
10	Notified Archaeological Monuments	None
11	Water bodies	None
12	Fence installation	None
13	Socio-economic factors	Small Village, next to the project site

14	List of Factories/industries within 10km radius	None yet, but the industries/factories that will come in the future since the area is designated as an industrial area in the Kigali Land Use Master Plan

2.4 Practice *a*nd challenges of solids waste

Solid waste management is the process of collection, storage, treatment and disposal of solid waste, generally making it harmless to humans, plants, animals, ecology and the environment. One of the biggest challenges facing solid waste in developing countries is its unhealthy disposal (Kofoworola, 2007). This was an issue recognized by all countries at the 1992 Conference on Environment and Development and was seen as a major obstacle on the road to sustainable development (UN, 1992). In Rwanda, personal/group awareness and attitudes toward waste generation and disposal are critical to meeting current solid waste management challenges.

A large proportion of municipal expenditures (up to 40%) are used to provide SWM services in developing countries, making this one of the most expensive sectors, contradictory, and cost different from the services provided, as they are still poor and inefficient (Mbuligwe, 2013).

In addition, there are other challenges: inadequate waste disposal sites and improper location, waste disposal and the introduction of foreign technologies (especially waste collection machinery). The SWM method is usually incompatible with local development due to different conditions and requirements (Mbuligwe, 2013). In many developing countries, the use of inappropriate places such as roads and unauthorized waste disposal sites is a common practice (Igbinomwanhia, 2011). Solid waste management is similar in most developing countries, including Rwanda.

The Republic of Rwanda has environmental challenges that have been faced by the population for decades. The environmental challenges in Rwanda are palpable in terms of land and wetlands degradation, water pollution, soil erosion, etc. Waste management is a big challenge in Rwanda, especially within urban areas. The solids waste generated from Kigali City is around 500 tons per day, of which between 300 and 350 tons/day is contrary collected. Only about 24% of those solids waste generated was disposed legally at Nyanza landfill. Now, that landfill is full and has been replaced by the newest called Nduba dumpsite. It is foreseen that in the incoming days, waste disposal will be a challenge due to the rapid increase of waste, which will be affected by the development and increase of population.

2.5 Anaerobic Digestion

Anaerobic digestion is a series of biochemical reactions through which different types of microorganisms decompose biodegradable materials to produce biogas, a form of clean energy. Almost all wastes with high concentrations of organic matter can be degraded by anaerobic biodegradation processes. As a by-product of the anaerobic process, biogas is an ideal renewable energy source that can alleviate some environmental problems associated with traditional energy sources (Mahir BozanÇağrı AkyolOrhan InceSevcan AydinEmail authorBahar Ince, 2017).

The biodegradable organic fraction of MSW includes food remains, yard trimmings, and paper. The microorganisms which degrade the organic waste, including protozoa, fungi, and bacteria, mineralize organic matter using carbon dioxide and methyl groups as electron acceptors in the absence of molecular oxygen (Chynoweth D.P, 1996). The products of anaerobic digestion are commercially viable. Methane especially constitutes about 60% by volume of the biogas produced from an anaerobic digester. It can be used directly as cooking, lighting, fuel for gas-powered vehicles or indirectly for electricity generation. The humus can be used as a soil conditioner.

2.5.1 Process Microbiology

Anaerobic digestion process involves several pathways for the decomposition of lignocellulose and other organic complexes and compounds to methane and other products. Several species of bacteria are involved in the overall reactions, which are depolymerization, fermentative acidogenesis, acetogenesis, acidogenic back reactions and methanogenesis (Chynoweth D.P, 1996). Methane is formed by methanogenic bacteria, which utilize acetate and hydrogen and carbon dioxide as the main substrates in the methanogenesis reactions.

In a well-functioning anaerobic digester, the bacterial population concentration should be higher than 1016 cells/ml (Amani, Nosrati and Sreekrishnan, 2010). This population usually consists of glycolytic, proteolytic and lipolytic bacteria and methanogens (Gerardi, 2006). Among these organisms, methanogens are known to be highly sensitive to their environment in terms of temperature, pH and concentration of certain compounds (ammonia, volatiles, fatty acids) (Manser, 2015).

2.5.2 Depolymerisation reactions

The first series of reactions that take place in anaerobic digestion are the depolymerization reactions, whereby the organic macromolecules are split up into smaller molecules. Depolymerization process can occur through various routes of which the main ones are hydrolysis and lysis (Chynoweth D.P, 1996). Extracellular enzymes secreted by hydrolytic and lysis bacteria mediate hydrolysis and lysis. Depolymerisation of lignocellulose, lipids, starch, and proteins converts them into a form that can be assimilated into the microbial cell and metabolized. The metabolites are mainly organic acids and carbon dioxide.

In the anaerobic digestion, depolymerization of the biodegradable organic matter is the slowest step and hence, the rate-limiting step in the overall process (Palmisano and Barlaz, 1996). Additionally, the efficiency of depolymerization dictates the ultimate methane yield. It is reported that about 50% of the organic matter remains undegraded due to inaccessibility of depolymerization enzymes to sites within the solid matrix of a lignocellulosic portion of the organic matter as well as the lack of appropriate organisms that secrete the essential enzymes (Chynoweth D.P, 1996).

2.5.3 Intermediate Reactions

Products of depolymerization are converted to fermentation products, which include propionate, butyrate, lactate, succinate, and alcohols. An acetogenic conversion of fermentation products to acetate and molecular hydrogen stops the accumulation of fermentation products (Chynoweth D.P, 1996).

On the other hand, when acetate accumulates, it causes a depression of pH in an anaerobic environment and this, in turn, inhibits acetogenic reactions by thermodynamic mechanisms. Another unique group of bacteria referred to as methanogenic bacteria corrects the situation. They utilize acetate, or molecular hydrogen and carbon dioxide as their principle substrates and in turn, reduce the levels of acetate and hydrogen (Chynoweth D.P, 1996).

Therefore, the overall anaerobic digestion process is dependent on the delicate balance between the activities of bacteria that form acetate and molecular hydrogen, often referred to as acetogens and obligate hydrogen-producing bacteria, and those that utilize these substrates called the methanogens. Under an environment where methanogenesis is optimum, the overall process of anaerobic digestion is only limited by the efficiency of the depolymerization step.

2.5.4 Methanogenesis

Methanogenic bacteria have numerous phenotypic characteristics which make them a unique group of microorganisms. Examples of these characteristics are metabolism, coenzyme and cell membrane lipids (Chynoweth D.P, 1996). Methanogenic substrates are several and include hydrogen, acetate, formate, methanol, carbon dioxide, manganese and others.

Their unique properties especially the CoM and F_{420} have been used to estimate their biomass in a given environment. Methanogenesis is the key microbial reaction leading to an imbalance of the anaerobic digestion in the event it is not optimized (Chynoweth D.P, 1996).

2.6 Factors affecting anaerobic digestion

Several factors affect the rates of different microbial activities involved in the process of anaerobic digestion. These factors include feedstock characteristics, loading rates, temperature, quality and quantity of anaerobic bacteria, microbial nutrients, mixing and the extent of pre-treatment.

2.6.1 Feedstock characteristics

The production and composition of municipal solid waste are affected by several factors, such as the extent of the area, the extent of recycling, the use of sinks, and the frequency of collection as well as the seasons and cultural practices. When considering MSW as a raw material for anaerobic digestion, it is important to note that the main components are paper, yard and food waste, which account for about 50% of the wet weight. This fraction can be increased considerably by encouraging source separation or using scavengers to remove recyclables. The latter is often practiced in developing nations.

MSW can be digested in an unsorted or sorted state (Pfeffer, 1974); (Pfeffer and Khan, 1976), but the degree of separation of organics influences materials handling and marketability of the residues as a soil conditioner (HASKONING, 1994) by removing undesired components such as plastics, glass, and heavy metals. The principle components in the organic fraction of MSW are lignin, cellulose, and hemicellulose, mainly from paper, yard and food waste. Owens and (Chynoweth D.P, 1996) have estimated that the ultimate methane yield for this kind of waste using first-order kinetics to be 0.2 m^3/kg VS.d.

Depending on the design of the anaerobic digester, the values of ultimate methane yield can reach as high as 0.35 m^3/kg.d (Rivard *et al.*, 1990). In circumstances where the temperature is maintained at thermophilic levels, higher values of ultimate methane yield, 0.6m^3/kg.d have been reported (Rintala and Ahring, 1994).

2.6.2 Loading rate

This is a parameter used to describe the application of feedstock to the anaerobic bacteria or the feed rate. It is expressed as the weight of feedstock (represented by volatile solids VS or chemical oxygen demand COD) per culture or bed volume of anaerobic digester per day (Chynoweth D.P, 1996). The loading rate accurately describes the amount of a feedstock required to provide the anaerobic bacteria sludge with a well-adapted microbial population to degrade within a specified time (usually one day), and the units are (KgVS or COD/ L.d). Starting from a given loading rate, the appropriate size of a digester utilizing the specific anaerobic bacteria sludge can be specified.

2.6.3 Anaerobic sludge

Anaerobic sludge is characterized by solids concentration or total solids content and volatile solids content as well. Total solids in the anaerobic sludge have a significant influence on the digester design, performance, and materials handling (Chynoweth D.P, 1996). Based on the total solids, one can have either low solids or high solids anaerobic digesters. Low solids have percentage total solids ranging from 2%TS to 10%TS, and high solids have total solids greater than 10%TS (Chynoweth D.P, 1996); (Rivard *et al.*, 1990).

Examples of low solids content anaerobic digesters are the conventional completely mixed anaerobic digesters which may be fed continuously, batch-wise or discontinuously. The feedstock for low solids anaerobic digesters is normally first diluted into 5%TS content (Maniatis *et al.*, 1987). Low solids digesters are bulky because they have to handle a considerable amount of water, and the digested slurry requires extra labor to de-water it before being put into final use.

The high solids content anaerobic digester is also referred to as solid-state fermentation (SSF). They have a unique set of advantages and limitations with regard to materials handling related to feeding applications mixing and effluent removal. Advantages include lower water requirements, dryer digested slurry, less energy requirements and permitting higher loading rates.

SSF can take place in a place in which mixing is possible or not (Baere, L. de ; Verstraete, 1984); (Rivard *et al.*, 1990).

Another type of anaerobic digester is based on the two-phase anaerobic digestion concept (Sambhunath Ghosh, 1975). In this digester, the first steps in the conversion of solid substrates, i.e. solubilization (depolymerization) and acidogenesis, are accomplished in the first phase while methanogenesis is allowed to occur in the second phase (Maniatis *et al.*, 1987). The two-phase anaerobic digester can comprise of two separate low solids type of digesters (Sambhunath Ghosh, 1975), or a combination of low and high solids anaerobic digesters (Deboosere *et al.*, 1988). However, this kind of anaerobic digester system faces rather severe technical problems, particularly at the site of feeding and unloading of the separate reactors (Deboosere *et al.*, 1988).

The total solids content in the anaerobic sludge is related to the quantity of the anaerobic bacteria that are available for degrading the organic matter. An estimate of these bacteria is made by determining the volatile solids fraction in the total solids content. It is taken to represent the cell dry weight of the available bacteria. In low solids digesters, the ratio of the available bacteria to the loading rate is about 10 times (Chynoweth D.P, 1996).

The digester design has an influence on the bacteria in various ways. For instance, how the feeding is administered can affect the population density of the bacteria in the digester. Continuously fed digesters pose a threat of bacteria washout, and with plug flow designs, the bacteria population is ensured by adding an inoculum with the feedstock (Chynoweth D.P, 1996). Low levels of bacteria population or too high loading rates can lead to an imbalance in the digester due to the more rapid growth of acid-forming bacteria as compared to methanogens and this, in turn, would lead to depression of the pH to inhibitory levels for the whole process of anaerobic digestion.

2.6.4 Temperature

Biological methanogenesis has been reported at temperatures ranging from 2^0C in marine sediments to over 100^0C near geothermal vents (Chynoweth D.P, 1996). However, anaerobic digestion has been performed mostly under ambient temperatures (20^0C-45^0C) called mesophilic or thermophilic temperatures (45^0C-65^0C) (Chynoweth D.P, 1996).

It has been shown that the process kinetics double for every 10^0C rise in temperature until some critical temperature (about 60^0C). In a study by (Aydin, Ince and Ince, 2015), in a series of experiments on anaerobic digestion at different temperatures, it was found that in the reactor, the physical partitioning of metabolic functions allowed for maximum microbial productivity and maximum total biogas production. Temperature is one of the most important operational factors in anaerobic biodegradation. All reactor configurations were successfully operated under conditions of psychrophilic (<25^{0}C), mesophilic (25-55) and thermophilic (>55^{0}). However, the stability of the microbial community was different in each case.

According to Chynoweth and (Chynoweth D.P, 1996), the thermophiles are genetically unique and do not survive at lower temperatures. Furthermore, they are more sensitive to temperature fluctuations outside their optimum range, and ammonia toxicity is more likely to occur in thermophilic digesters than in mesophilic digesters. It can, therefore, be expected that more effort is required to ensure stable performance for a thermophilic digester than for a mesophilic one.

Both low solids and high solids digesters can be operated under thermophilic or mesophilic temperatures. However, extra heating is required for the low solids digester because of the high amount of water (BAETEN and VERSTRAETE, 1993). The mechanism by which temperature affects the process of anaerobic digestion is related to the enzymatic activities occurring in the process. Temperature affects the rates of these activities. (Chynoweth D.P, 1996) has shown that the reduction of volatile fatty acids is higher at 55^{0}C than at 35^{0}C.

Thermophilic anaerobic digestion showed that higher organic matter degradation (especially fiber), the methane (CH4) yield as well as better percentage of ultimate CH4 yield, are higher for thermophilic conditions when compared with mesophilic conditions (Moset *et al.*, 2015), (İnce, İnce and Önkal Engin, 2017). However, the sludge settleability of the mesophilic treatment is better than that of the thermophilic treatment (İnce, İnce and Önkal Engin, 2017). In addition, thermophilic digesters can accommodate higher loading rates (Six and De Baere, 1992).

2.6.5 Others

Other factors which can affect anaerobic digestion significantly include the level of microbial nutrients and the degree of mixing in the digester as well as the form of pre-treatment of the feedstock prior to the anaerobic digestion. Nitrogen and phosphorous are the major nutrients required for the process. A ratio of carbon to nitrogen of above 25 in the anaerobic substrate results in nitrogen being the limiting nutrient (BAETEN and VERSTRAETE, 1993). Other nutrients needed in intermediate concentrations include sodium, potassium, calcium, magnesium, chloride, and sulfur. A host of micro-nutrients has been identified. (Chynoweth D.P, 1996).

Mixing is thought to optimize the process of anaerobic digestion by enhancing interaction between cells and substrates and removing the inhibitory metabolic products from the cells (Chynoweth D.P, 1996) (Maniatis *et al.*, 1987). Depending on the type and configuration of the digester, mixing can be achieved by mechanical stirring, leachate recycling or gases recycle. In another digester design (Six and De Baere, 1992), the inoculum is mixed with the feed and then subjected to plug flow form of feeding. Mixing requires energy and therefore, affects the process of anaerobic digestion in relation to the energy balance.

Treatment of the feedstock prior to anaerobic digestion enhances materials handling and microbial conversion. Pre-treatment can involve separation of solid-liquid fractions by settling floatation or pressing, removal of non-biodegradable components, particle size reduction, thermal heating, chemical treatment, irradiation and enzymatic treatment (Chynoweth D.P, 1996). In general, it can be said that while most methods improve the rate and to a limited degree, the efficiency of conversion, the benefits do not justify the added cost of the pre-treatment systems.

2.6.6 Control parameters

Parameters, which can be used to monitor the process of anaerobic digestion include methane yield, organic matter conversion efficiency as expressed by the VS or COD reduction, VFA levels, pH in the digester and redox potential. Methane production is a measure of the process kinetics and is often expressed as volume of methane per volume of digester per day. (lCH4/L.d). It is a product of loading rate (Kg VS or COD/ L.d) and methane yield (lCH_4/KgVS or COD).

A typical methane yield of 0.2m^3/Kg VS corresponds to a VS reduction of about 50% (Chynoweth D.P, 1996). Values of methane production rate ranging from 1 to 5 lCH_4/ L.d have been reported (Chynoweth D.P, 1996). Methane content in the biogas is a good indicator of the stability of the anaerobic digester. It is said to be a function of the H/C ratio and lies within the range 50-60% v/v(Chynoweth D.P, 1996). A decrease in methane content from 50-60% shows the digester is unstable since the methanogenic activity is the key factor leading to digester failure. PH and VFA influence digester performance. When methanogenic activity is not optimum, VFAs accumulate and at levels greater than 10,000mg/l, anaerobic digestion process can be inhibited (Chynoweth D.P, 1996).

2.6.7 Relationship between methane generation and organic matter

2.6.7.1 Step 1: Calculation of COD equivalent of CH4

CH4 + $2O_2$ ------------------> $CO_2 + 2H_2O$

We can use chemistry to calculate units mass for each constituent in methane combustion (equation 1) unit masses must balance on both sides equation 1 putting a number to the equation:

16g + 2x32g = 44g +2x18g

The mass of one mole of methane is 16g. The 2 moles of O_2 has a mass of 64g. So, each gram of methane represents 4grams of OD (Oxygen Demand). Chemical Oxygen Demand (COD) is used to determine OD for anaerobic digestion.

=>16 g CH_4 ~ 64 g O_2 (COD) ------------------> $CO_2 + 2H_2O$

=>1 g CH_4 ~ 64/16 = 4 g COD -------------- (Eq.1)

2.6.7.2 Step 2: Conversion of CH_4 mass to equivalent volume

Based on gas law, 1 mole of any gas at STP (Standard Temperature and Pressure) occupies a volume of 22.4 L.

=> 1 Mole CH_4 ~ 22.4 L CH_4

=> 16 g CH_4 ~ 22.4 L CH_4

=> 1 g CH_4 ~ 22.4/16 = 1.4 L CH_4 ---------- (Eq. 2)

Equation 2 provides a valuable model of the relations between mass and volume in a gas.

2.6.7.3 Step 3: CH_4 generation rate per unit of COD removed

From eq. (1) and eq. (2), we have,

=> 1 g CH_4 ~ 4 g COD ~ 1.4 L CH_4

=> 4 g COD ~ 1.4 L CH_4

=> 1 g COD ~ 1.4/4 = 0.35 LCH_4

or

=>1 Kg COD ~ 0.35 m^3 CH_4 --------------- (Eq. 3)

Equation 3 predicts the volume of methane released per mass of oxygen demand removed and gives estimates of the amount of organic matter that will be converted to CH_4 during the digestion.

Complete anaerobic degradation of 1 Kg COD produces 0.35 m^3 CH_4 at STP

2.6.8 Existing Digester Designs

As mentioned earlier, anaerobic digesters can be broadly classified into three categories: low solids content digesters, high solids content digesters, and two-phase anaerobic digesters. Within each category, further classification based on the type of mixing, temperature, and mode of feeding can be identified.

High solids digesters achieve high loading rates and minimize costs of de-watering the digested slurry as well as water requirements. However, it poses a great challenge in starting, feeding and mixing.

A low solids anaerobic digester requires less power for mixing but poses bulkiness problems due to the high amount of water content as well as increased costs of de-watering the digested slurry. In addition, (Deboosere *et al.*, 1988) have shown that the formation of a hard scum layer on top of the digester slurry is an often encountered practical problem.

The two-phase digester attempts to reduce the anaerobic digestion time by allowing the solubilization and acidification bacteria to operate in the 1st phase and the sensitive groups of bacteria (the acetogens and the methanogens) to operate in the 2nd phase. Major advantages of the multiphase digesters include improved stability, the concentration of the slow-growing acetogens and methanogens and the production of biogas with higher methane content since most of the carbon dioxide has been released in 1st phase (Chynoweth D.P, 1996). However, it has one disadvantage, which is related to the complexity of the design and operation.

2.6.9 Biogas process

Biogas processes are processes in which organic matter is cooperatively decomposed between several different types of microorganisms. The figure below shows the different steps of the biogas process.

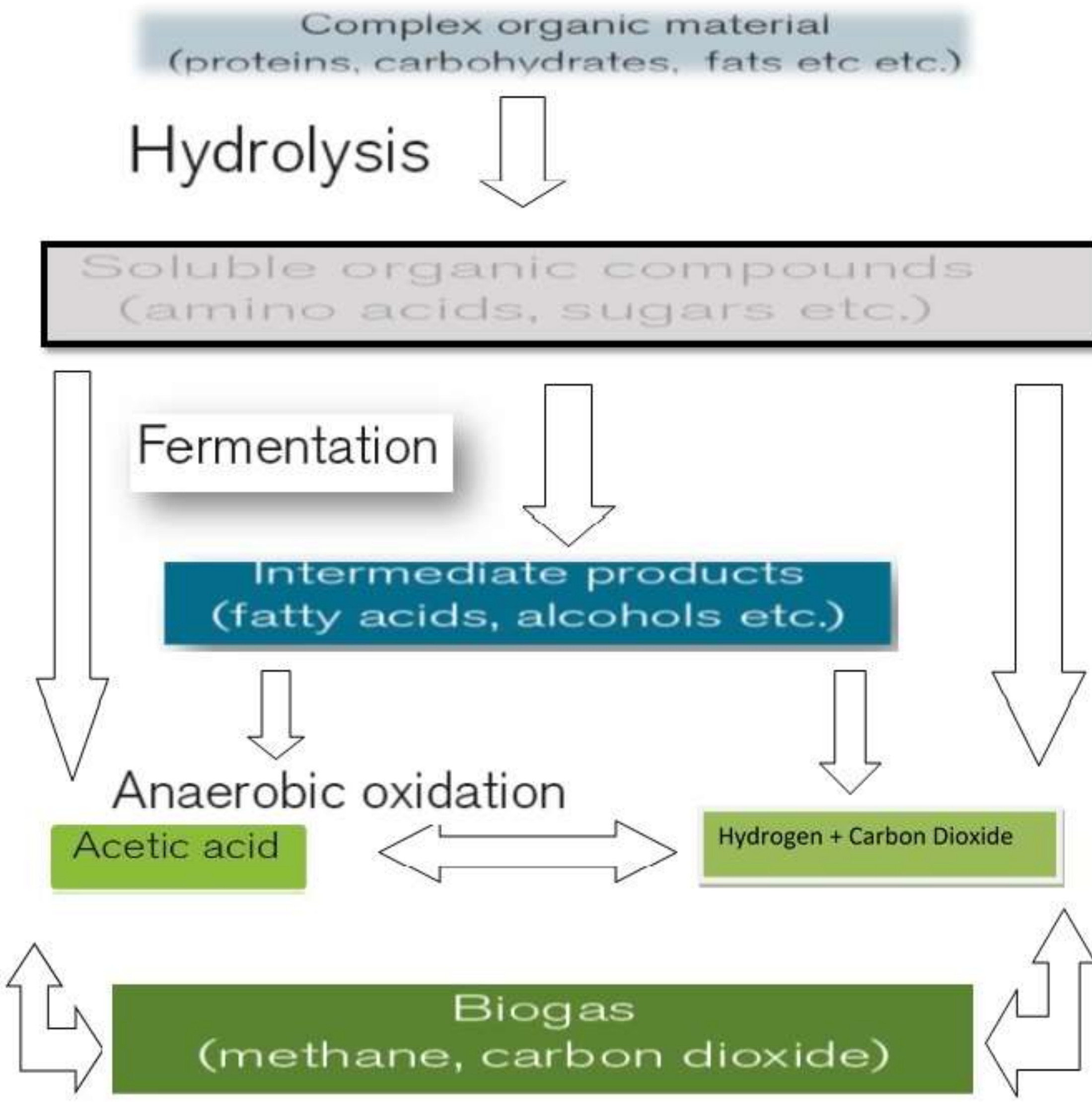

Figure 2: The biogas process divided into a number of stages that take place during digestion, (illustration: Energigas Sverige)

2.6.10 Cost-benefit analysis of biogas and electric energy production

Electricity production from the bioenergy sector shows that in recent years, Italy (2001-2014) has increased by an average of 19% per year, from 1 958 to 18 732 GWh (Salerno *et al.*, 2017). In 2014, it accounted for 15.5% of total renewable energy production. The increase in biogas energy production is relevant: it rose from 1,665 GWh in 2009 to 8,198 GWh in 2014 (Salerno *et al.*, 2017). In this case, the greatest growth involves the use of biogas plants from animal feces (Mwesigye *et al.*, 2009).

Business decisions regarding the construction of anaerobic digestion equipment on farms almost always involve expensive investments (Salerno *et al.*, 2017). Even in smaller companies, significant investment costs cannot be resolved without a clear profitability framework and the changes identified in the production and management identities of this technology (Salerno *et al.*, 2017). In addition to technical aspects, entrepreneurs should be able to assess the sensitivity of investment profitability, such as Patrizio and China (2016) changes in active projects such as electricity, incentive prices and the incidence of public donations (Salerno *et al.*, 2017).

Considering the payback period, farmers can (Di Giacinto, S., A. Colantoni, M. Cecchini, D. Monarca, R. Moscetti, R. Massantini, 2012) get the economic benefits of repaying their work and investment (Holm-Nielsen, J. B., 2009) (Karellas, S., 2010), etc. The use of deep cost-benefit analysis, the introduction of anaerobic digestion techniques (Piccinini, S., G. Bonazzi, C. Fabbri, D. Sassi, M. Schiff, M. Soldano, 2008).

2.7 Conclusion

Rwanda is a developing country where the population living in cities is growing. Urbanization leads to the increase of municipal solid waste generation and energy consumption. Anaerobic digestion technology can be a solution to both municipal waste and energy situations.

According to research on municipal solid waste management in the City of Kigali, researchers have found that waste is not stored or collected properly. This can cause environmental and health problems. However, the City of Kigali uses different techniques to manage household solid waste by recycling it, turning it into compost and briquettes, which greatly helps to reduce the amount of waste. Despite recycling and recovery efforts, the waste recovery rate in Rwanda remains relatively low.

According to the Rwanda Energy Group (REG) statistics on households accessing electricity, accessibility has been improved, but the goal of electrification is not yet achieved. Rwanda wants 100% of the population to access electricity. However, for the moment, electrification remains below 50%. The electricity deficit in Rwanda can be bridged by introducing anaerobic digestion technology and producing biogas from organic waste, which will contribute to the generation of electricity and will have an economic benefit for the whole country.

3 MATERIALS AND METHOD

3.1 Municipal waste generation survey

3.1.1 Study area

A solid waste generation survey was carried out in 6 selected villages of Nyarugenge sector, in the Nyarugenge district of Kigali City municipality. These are Ganza, Muhabura, Biryogo, Umurimo, Umucyo, and Umurava.

2.1.1. Survey areas and sample sizes

The selected areas where the survey was carried out and the number of the areas under each class organization as well as the size of the samples that were considered are listed in Table 3-1 below.

Table 4: The selected areas where the survey was carried out

Upper class,	KIYOVU	GANZA	10 houses
		MUHABURA	10 houses
Middle class,	BIRYOGO	BIRYOGO	10 houses
		UMURIMO	10 houses
Lower class.	AGATARE	UMUCYO	10 houses
		UMURAVA	10 houses

2.1.1. The geographical location of survey areas

Rwanda is located in central Africa, to the east of the Democratic Republic of the Congo, at the co-ordinates 2°00′S 30°0′E. At 26,338 square kilometers (10,169 sq mi), Rwanda is the world's 149th-largest country.

Nyarugenge is a district (Akarere) in Kigali Province 1° 59′ 0″ S, 30° 1′ 0″ E, Rwanda at 134 km². Its heart is the city center of Kigali (which is towards the west of the urban area and the province), and it holds most of the city's businesses. Among 4 districts, is divided into 10 sectors (Imirenge): Gitega, Kanyinya, Kigali, Kimisagara, Mageragere, Muhima, Nyakabanda, Nyamirambo, Nyarugenge and Rwezamenyo.

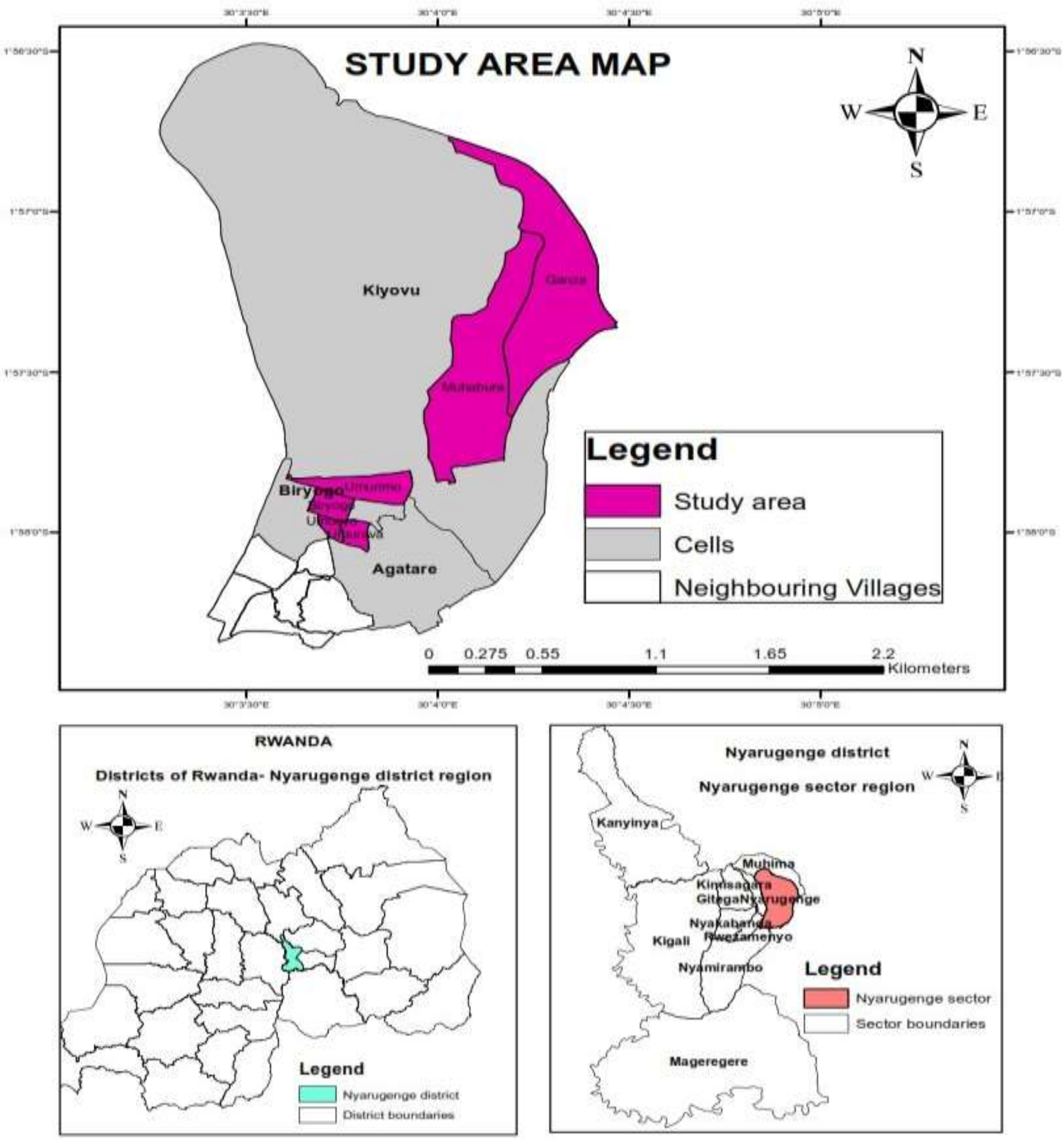

Figure 3: Case Study (Area of Nyarugenge District)

3.1.2 Survey methodology

The surveyed area was classified according to classes. The reason for categorizing the residential area is that the garbage quantity and composition is related to socioeconomic factors. The survey was carried out in Nyarugenge Sector of Nyarugenge District with three selected cells. In each cell, two villages were selected randomly, and in each village, 10 houses were surveyed.

In each of the survey villages, the sample size that was surveyed comprises 5-10% of the families within the designated villages. According to (Colwell, Rahbek and Gotelli, 2004), when the sample size is as large as 5-10 times the size of the population, chi-square (X2) which is the measure of randomness holds true, hence reflecting the pattern consistent with the population being examined. However, low sample sizes (e.g. less than 5 times the size of the population) cause deviations in the observation due to temporal and/or spatial variations and can result in the exaggerated pattern being the output.

Table 5: Distribution (count) of the resident population of Nyarugenge district in 2012 by sector, sex, and density (NSIR, 2012)

Sector	Both sexes	Male	Female	% Female	Population share (% of the total population)	Density (Inhabitants /km^2)
Rwanda	**10,515,973**	**5,064,868**	**5,451,105**	**51.8**		415
Kigali city	**1,132,686**	**586,123**	**546,563**	**51.7**		**1,552**
Nyarugenge district	**284,561**	**148,132**	**136,429**	**47.9**	**100**	2,149
Gitega	28,728	14,989	13,739	47.8	10.1	24,482
Kanyinya	21,859	10,777	11,082	50.7	7.7	904
Kigali	30,023	15,375	14,648	48.8	10.6	1,022
Kimisagara	46,753	24,451	22,302	47.7	16.4	14,116
Mageragere	23,407	11,482	11,925	50.9	8.2	428
Muhima	29,768	17,222	12,546	42.1	10.5	10,115
Nyakabanda	25,666	13,351	12,315	48.0	9.0	10,589
Nyamirambo	40,292	20,290	20,002	49.6	14.2	4,608
Nyarugenge	21,302	11,477	9,825	46.1	7.5	4,605
Rwezamenyo	16,763	8,718	8,045	48.0	5.9	16,328

The survey was conducted every week for four weeks correspond to a month, to estimate the quantity of municipal waste discharge over a day. Moreover, this survey was conducted between 24/June and 20/July. The sorting-and-weighing methodology was used for assessing the waste composition from each of the sample households for each week. In the survey, the amounts of solid waste generated and disposed of in each the survey areas (villages) was quantified. The methodology has the advantage of greater accuracy. (The staff helped in the collection of the data). In addition, physical characterization of the solid waste streams to establish the various waste components that were generated in each of the sample household units in the survey areas was done. The types of solid waste components and their physical state were examined in detail.

3.1.3 Survey duration and manpower requirements

Table 6: Estimate of the time period needed for carrying out all the phases of the solid waste generation survey

Survey Area	Sample Size (5-10%)	No. of household surveyed	Time (h) for weekly solid waste collection and weighing	Time (h) for sorting and classification of the solid waste	Total time (h) for the survey per week
GANZA	63	10	4	48	52
MU-RA	62	10	4	48	52
BI-GO	127	10	4	48	52
U-MO	143	10	4	48	52
U-CYO	39	10	4	48	52
U-VA	81	10	4	48	52

3.1.4 Material requirement

The weighing balance was used for weighing the garbage generated from each model house in Kigali City. A scale having the accuracy of up to 100g was used so that the reliable weight of the lightest refuse could be measured. The total mass of garbage from each model house was weighted prior to sorting, and then two sacks were used for sorting the organic and inorganic waste. The organic waste was placed in a green sack and inorganic waste in a blue sack. Furthermore, the other types of municipal waste were identified. The same procedure was adopted weekly over the study period.

Rubber gloves were used for hands protection and dust masks for respiratory protection. The results were recorded in a tabular format.

3.2 Physical-chemical and biological characteristics

3.2.1 Physical-Chemical Characteristics of Feedstock

The physical-chemical characteristics determined were dry matter content (DM), volatile solids content (VS), chemical oxygen demand (COD), and BOD_5. The samples used for determination of COD and BOD_5^{20}, were first subjected to particle size reduction by chopping them into small pieces with a knife. Further particle size reduction and solubilization were effected by the use of a domestic kitchen knife and de-ionized water.

3.2.1.1 Dry Matter Content (DM) and Volatile Solids (VS)

The dry matter content of a feedstock was determined by drying a pre-weighed sample of raw waste at 105^0C until a constant weight was achieved. Effectively, it is the residue left after evaporating the water from a sample volume and drying the residue in a kiln until a constant weight is obtained. The weight of the residue over the weight of the wet sample expressed in percentage is referred to as the Dry Matter content (DM).

The volatile solids content of a sample is the difference between the ash content and the Dry Matter content divided by the total solids content, all expressed in percentage. The ash content is defined as the residue left after incinerating the dry sample at 450^oC-600^oC.

Both DM and VS determination was carried out according to standard methods for the examination of water and wastewater as described by (Greenberg, D.C., J.H. Williams, 1992).

3.2.1.2 Chemical oxygen demand (COD) of Feedstock

A 100 g sample was taken from each digester for testing to produce a suspension of organic material of solid organic material, and the sample was cut into very small pieces. Dilute the sample to the desired concentration, pipette, and use a 15 mL plastic vial. In addition, a 10 mL glass vial and cap are required to perform a COD test on the diluted sample.

The chemicals added to the 20ml of diluted organic waste to test for
COD included:

- 30 mL conc. sulphuric acid solution
- 10ml of potassium dichromate solution
- 40g/L mercuric Sulfate (Punch)

In addition to these chemicals, vortex reactors (150 ° C) and spectrophotometers are required to test COD. Finally, data were organized using Microsoft Excel and COD (kg/kg dry waste) was calculated based on the absorbance values provided by the spectrophotometer.

Absorbance measurement produced by the spectrophotometer is converted to grams per liter of COD using a calibration curve. This value can be converted to COD (kg/kg dry waste) by multiplying the sample's COD (kg / L) by the known sample concentration (kg / L): COD determination was performed according to standard methods for the examination of water and wastewater as described by (Greenberg, D.C., J.H. Williams, 1992).

3.2.1.3 Biochemical oxygen demand (BOD) of Feedstock

An amount of sample from different digesters with chopped particles into small pieces was taken. Dilution water was aerated before adding the nutrient solution. Manganous Sulphate solution ($MnSO_4.4H_2O$), Winkler ($MnSO_4$), Sodium Thiosulphate ($Na_2S_2O_3.5H_2O$), sulphuric acid, and starch indicator were prepared. 125 ml BOD bottles were used, assorted glass with 200mL and 50ml glass cylinder were used and the sample was diluted with 1mg of the sample to each liter of diluted water. 10 mL of Manganous Sulfate, 10mLof Winkle and 10mL of Sulphilic acid were added to the sample contained in the bottle. A sample of 50mL was titrated with Thiosulphate Solution after adding the indicator.

The incubator was calibrated at 20°± 1°C; after measuring initial DO concentration (D_1) the sealed BOD sample was placed in the air incubator, and the sample was incubated at 20°C ± 1°C for 5 days. At the end of 5 days ± 4 hours and the final DO concentration (D_2) was measured. Finally, BOD_5 was computed as (DO_0 days - DO_5 days). The methodology used for this test was titration.

BOD determination was performed according to Five-day biochemical oxygen demand as described by (Delzer and Mckenzie, 2003).

3.2.2 Physical-Chemical Characteristics of Lab-scale Digester Slurry

The physical-chemical characteristics determined were dry matter content (DM), volatile solids content (VS), chemical oxygen demand (COD), BOD_5, Samples used for determination of COD and BOD_5^{20}, were first subjected to particle size reduction by chopping them into small pieces with a knife. Further particle size reduction and solubilization were affected by the use of a domestic kitchen knife and de-ionized water.

3.2.2.1 Dry Matter Content (DM) and Volatile Solids (VS)

The dry matter content of a feedstock was determined by drying a pre-weighed sample of raw waste at 105^0C until a constant weight was achieved. Effectively it is the residue left after evaporating the water from a sample volume and drying the residue in a kiln until a constant weight is obtained. The weight of the residue over the weight of the wet sample expressed in percentage is referred to as the Dry Matter content (DM).

The volatile solids content of a sample is the difference between the ash content and the Dry Matter content divided by the total solids content all expressed in percentage. The ash content is defined as the residue left after incinerating the dry sample at 450^oC-600^oC. Both DM and VS determination was carried out according to standard methods for the examination of water and wastewater as described by (Greenberg, D.C., J.H. Williams, 1992).

3.2.2.2 Chemical oxygen demand (COD) of Feedstock

A 100 g of the sample from each digester was taken for the test to create the suspension of organic matter of solid organic material the sample was chopped into very small pieces. The samples were diluted to the required concentration, a pipette, and 15 mL plastic vials were used. Additionally, 10 mL glass vials and caps were needed in order to perform the COD test on the diluted sample.

The chemicals added to the 20ml of diluted organic waste to test for
COD included:

- 30 mL conc. sulphuric acid solution
- 10ml of potassium dichromate solution
- 40g/L mercuric Sulfate (Punch)

Further to these chemicals, a vortex, reactor (150°C), and spectrophotometer were required to test for COD. Finally, Microsoft Excel was used to organize the data and to calculate the COD (kg/kg dry waste) from the absorbance values provided by the spectrophotometer.

The spectrophotometer produces measures of absorbance, which are converted into grams per liter of COD using a calibration curve. This value can be converted into COD (kg/kg dry waste) by multiplying the COD of the sample (kg/L) by the known sample concentration (kg/L): COD determination was performed according to standard methods for the examination of water and wastewater as described by (Greenberg, D.C., J.H. Williams, 1992).

3.2.2.3 Biochemical oxygen demand (BOD) of Feedstock

An amount of sample from different digesters with chopped particles into small pieces was taken. Dilution water was aerated before adding the nutrient solution. Manganous Sulphate solution ($MnSO_4.4H_2O$), Winkler ($MnSO_4$), Sodium Thiosulphate ($Na_2S_2O_3.5H_2O$), sulphuric acid, and starch indicator were prepared.125 ml BOD bottles were used, assorted glass with 200mL and 50ml glass cylinder were used and the sample was diluted with 1mg of the sample to each liter of diluted water. 10 mL of Manganous Sulfate, 10mLof Winkle and 10mL of Sulphilic acid were added to the sample contained in the bottle.

A sample of 50mL was titrated with Thiosulphate Solution after adding the indicator. The incubator was calibrated at 20°± 1°C; after measuring initial DO concentration (D_1) the sealed BOD sample was Place in the air incubator and the sample was incubated at 20°C ± 1°C for 5 days. At the end of 5 days ± 4 hours and the final DO concentration (D_2) was measured. Finally, BOD5 was computed as (DO_0 days - DO_5 days). The methodology used for this test was titration. BOD determination was performed according to Five-day biochemical oxygen demand as described by (Delzer and Mckenzie, 2003).

3.2.3 Lab Scale Anaerobic Digester

3.2.3.1 Description of Lab Scale Anaerobic Digester

The lab-scale anaerobic digester was set up in the laboratory to determine the quality of organic fraction of municipal solid waste with regard to biogas production. The set-up consists of three conical flask digesters with 5000 ml capacity with each having a graduated water column of a clear Perspex glass cylinder with 100 mm diameter and 2000 mm height placed in a 20 l buckets (wide mouth basin) as biogas collectors. Each conical flask is closed with a tightly fitting cork (rubber) flask stopper fitted with a 4mm diameter biogas outlet tube rubber pipes.

The biogas produced is collected over a graduated water column, which was colored with methyl orange crystals. Each glass cylinder is connected with biogas inlet and biogas outlet rubber pipe. Fastener clips (Perspex glass) are provided to allow the opening and closing of the rubber tubing pipes. Figure 3.1 shows the experimental set-up

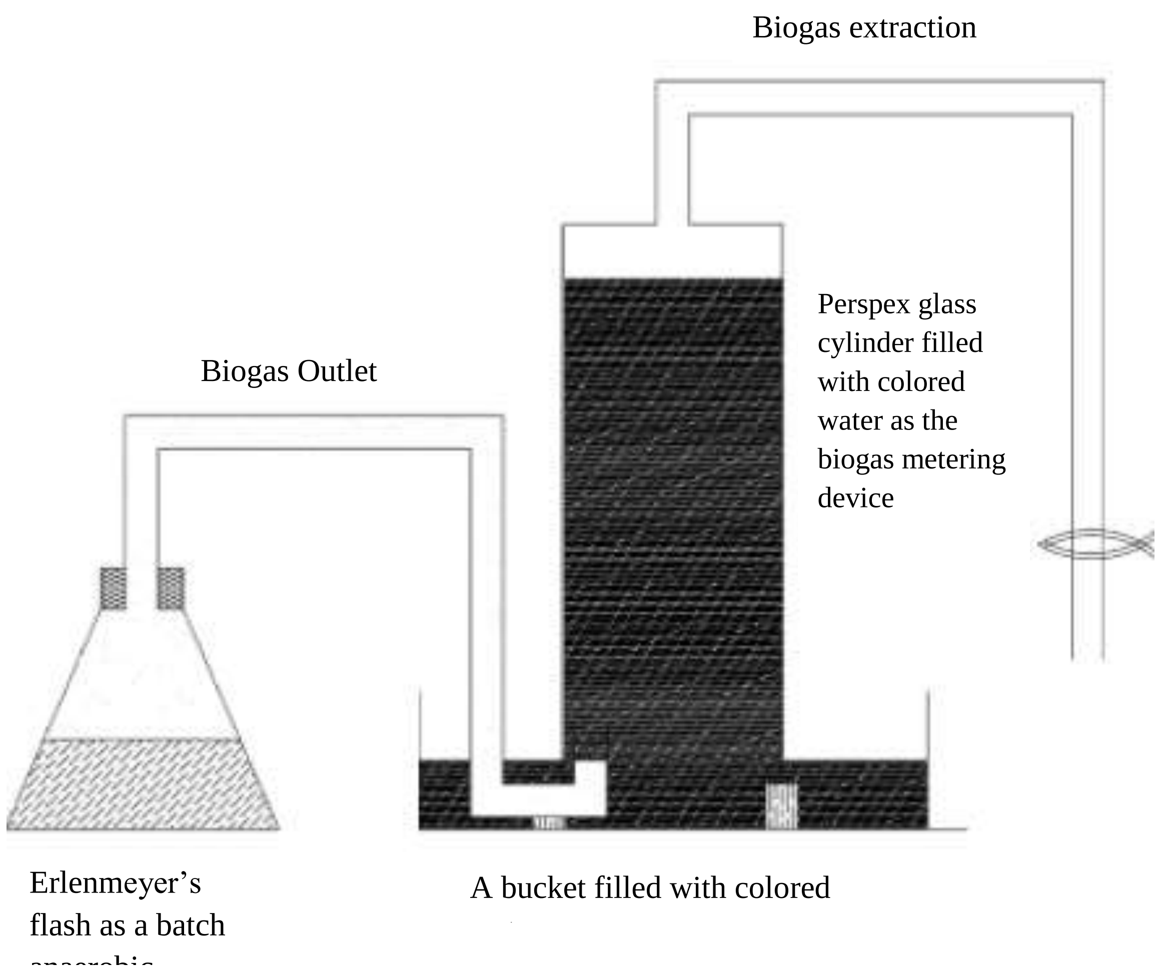

Figure 4: Experimental set-up for low solids batch anaerobic digester

Figure 5: Experimental set-up for low solids anaerobic digestion

3.2.3.2 Digester start-up and operation

A mixture of 1-2 kg of wet cow dung was used as an inoculating medium to obtain stable conditions for the production of biogas and diluted with about 500ml of distilled water to produce slurry. Distilled water was used to avoid the toxicity to methane-producing bacteria by the organochlorines contained in tap water following the treatment of drinking water by the water service providers.

The digesters were allowed to acclimatize for about 7 days and then each was loaded with a mixture of 200 gm of kitchen waste (food remains) premixed with about 75 ml of distilled water every 3 days. The food remains were chopped into small pieces into slurry-like feedstock and weighed on a scale balance to obtain the weight in grams. Before mixing the chopped waste with distilled water, a sample of about 50 grams was placed in a dry pre-weighed crucible for the purpose determination of the dry matter content, ash content, chemical oxygen demand (COD) and biological oxygen demand (BOD). Then, each of the digesters was shaken well and thereafter, tightly capped to ensure no air got in.

3.2.3.3 Biogas analysis

The Geotech Biogas 5000 portable biogas analyzer was used to determine the biogas produced, as well as its constituents: methane, carbon dioxide, dioxide, hydrogen sulfide ($CH4$, $CO2$, $O2$, $H2S$, Bal). The apparatus was selected for use because it is easy to use, calibrate and configure, and it allows for consistent data collection for improved analysis and accurate reporting while helping to verify that the digester process works efficiently.

Figure 6: The Geotech Biogas 5000 portable biogas analyzer

4 RESULTS AND DISCUSSION

4.1 Waste generation survey

The sample of MSW from each weekly collection was taken to estimate the amount of municipal solid waste generated in Kigali City. The tables below show the different data collection from three cells in Nyarugenge: AGATARE (Lower class), BIRYOGO (middle class), KIYOVU (high class).

Table 7: Agatare Cell - Umucyo Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	5.6	4.2	3.2	1.1	14.1	2%
Papers	6.2	3.1	2.9	2.2	14.4	2%
Cartons	3.9	2.2	0.7	2	8.8	1%
Glasses	2.7	0.1	0.3	0.3	3.4	0%
Metals	3.7	1.9	1.9	0.415	7.915	1%
Biodegradable Organic waste	203.5	181.8	123.4	125.2	633.9	81%
Others (clothes, shoes, bones, hair, pampers.)	29	32.1	23	18.8	102.9	13%

Table 7 summarizes the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses of AGATARE cell - UMUCYO Village. Over 785.415 kg of waste generated in this cell, the waste components were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, Biodegradable organic waste, and others waste respectively.

Organic waste formed the highest fraction, 81% of the entire waste stream from this cell, and Glasses were not found as part of waste in this village. The higher and lower generation rate of organics waste, glasses respectively could be attributed to the socio-economic activities in the area.

Table 8: Agatare Cell - Umurava Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	2.8	2.4	3.2	1.9	10.3	1%
Paper	1.3	5	1.6	0.9	8.8	1%
Cartons	6	1.8	0.9	1.2	9.9	1%
Glasses	5	2.1	2.4	2.8	12.3	1%
Metal	0.9	4.2	1.3	0.9	7.3	1%
Biodegradable Organic waste	175	174.5	162.5	140	652	73%
Others (clothes, shoes, bones, hair, pampers.)	37.5	46.5	57	53	194	22%

Table 8 shows the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses of AGATARE CELL - UMURAVA VILLAGE. Over 894.6 kg of waste generated in this cell the waste components were 1%, 1%, 1%, 1%, 1%, 73%, 22% for plastics, papers, cartons, glasses, metal, biodegradable organic waste, and others waste respectively.

Organic waste formed the highest fraction, 73% of the entire waste stream from this cell. The higher generation rate of organics waste could be attributed to the socio-economic activities in the area.

Table 9: Biryogo Cell - Biryogo Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	7.1	3.35	3	4.7	18.15	2%
Paper	9	5.1	2.9	4.2	21.2	2%
Cartons	3.3	1.81	3.7	2.9	11.71	1%
Glasses	0.01	0.01	0	0	0.02	0%
Metal	1	0.38	0.4	1.48	3.26	0%
Biodegradable Organic waste	190	146.3	161	163	660.8	78%
Others (clothes, shoes, bones, hair, pampers)	23.2	25	57.7	27.5	133.4	16%

Table 9 shows the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses of BIRYOGO CELL - BIRYOGO VILLAGE. Over 848.54 kg of waste generated in this cell, the waste components were 2%, 2%, 1%, 0%, 0%, 78%, 16% for plastics, papers, cartons, glasses, metal, biodegradable organic waste, and others waste respectively.

Organic waste formed the highest fraction, 78% of the entire waste stream from this cell, and Glasses and metals were not found as part of waste in this village. The higher and lower generation rate of organics waste, (glasses and metals) respectively could be attributed to the socio-economic activities in the area.

Table 10: Biryogo Cell - Umurimo Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	7.5	3.5	3	3.7	17.7	2%
Paper	8.7	3.9	4.8	4.4	21.8	3%
Cartons	2.8	3.3	3.9	5.4	15.4	2%
Glasses	0	0	0.5	0	0.5	0%
Metal	3	1.01	0.27	10.41	14.69	2%
Biodegradable Organic waste	123.5	151	161	148	583.5	78%
Others (clothes, shoes, bones, hair, Pampers)	7.7	19.9	37.2	25.8	90.6	12%

Table 10 shows the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses of BIRYOGO CELL - UMURIMO VILLAGE. Over 744.19 kg of waste generated in this cell, the waste components were 2%, 3%, 2%, 0%, 2%, 78%, 12% for plastics, papers, cartons, glasses, metal, Biodegradable organic waste, and others waste respectively.

Organic waste formed the highest fraction, 78% of the entire waste stream from this cell and Glasses were not found as part of waste in this village. The higher and lower generation rate of organics waste, glasses respectively could be attributed to the socio-economic activities in the area.

Table 11:Kiyovu Cell – Ganza Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	17	10.7	8.9	6.2	42.8	9%
Paper	9	1.6	6.5	2.3	19.4	4%
Cartons	29	4.5	6.4	2.6	42.5	9%
Glasses	21.5	6.5	7	6.2	41.2	9%
Metal	6	5.8	0.5	1.1	13.4	3%
Biodegradable Organic waste	76	55	68	76.5	276	59%
Others (clothes, shoes, bones, hair, Pampers.)	0	13	12.5	4.2	29.7	6%

Table 11 shows the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses for KIYOVU CELL – GANZA VILLAGE. Over 465 kg of waste generated in this cell the waste components were 9%, 4%, 9%, 9%, 3%, 59%, 6% plastics, papers, cartons, glasses, metal, Biodegradable organic waste, and others waste respectively. Organic waste formed the highest fraction, 59% of the entire waste stream from this cell and this fraction was less than other villages. The reason is that they manage organic waste by using them for their gardens as fertilizer.

Table 12:Kiyovu Cell – Muhabura Village

Waste Components	**Quantities (Kg) For 10 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 10 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	24	20.3	15.5	15	74.8	16%
Paper	12	5.50	9.5	9	36	8%
Cartons	10.7	10.60	11	2.5	34.8	8%
Glasses	5	0.02	5.2	7	17.22	4%
Metal	5	2	1.3	2.5	10.8	2%
Biodegradable Organic waste	86.5	63.7	50	47	247.2	54%
Others (clothes, shoes, bones, hair, Pampers.)	9	9.2	9	6	33.2	7%

Table 12 shows the various fractions of the MSW and their percentage generation rate collected during 4 weeks from ten (10) houses of KIYOVU CELL – MUHABURA VILLAGE. Over 454.02 kg of waste generated in this cell, the waste components were 16%, 8 %, 8%, 4 %, 2 %, 54 %, 7% for plastics, papers, cartons, glasses, metal, biodegradable organic waste, and others waste respectively.

Organic waste formed the highest fraction, 54% of the entire waste stream from this cell and this fraction was less than other villages. The reason is that they manage organic waste by using them for their gardens as fertilizer.

According to this survey, the average waste generated from the various types of households in Kigali city is summarized in Table below:

Table 13: Sectors' summary

Waste Components	**Quantities (Kg) For 60 Households On Weekly Basis**				**Quantity of individual components collected for 4 weeks from 60 households**	**Percentage of the individual component in the entire waste stream**
	W1	**W2**	**W3**	**W4**		
Plastics	64	44.45	36.8	32.6	177.85	4%
Paper	46.2	24.2	28.2	23	121.6	3%
Cartons	55.7	24.21	26.6	16.6	123.11	3%
Glasses	34.21	8.73	15.4	16.3	74.64	2%
Metal	19.6	15.29	5.67	16.805	57.365	1%
Biodegradable Organic waste	854.5	772.3	725.9	699.7	3053.4	73%
Others (clothes, shoes, bones, hair, Pampers.)	106.4	145.7	196.4	135.3	583.8	14%

Table 13 shows the summary of complete survey data of solid waste in Kigali City generated from different categories of model houses. The table shows different fractions of solid waste generated from surveyed villages during the survey period of 4 weeks. From table 4.1.7, it was seen that the waste generated from the households, the organic wastes are most generated at a rate of 73%.

Table 14: Total quantity of Municipal solid waste generated in Kigali city

	Quantity of Municipal Solids waste for Surveyed Households (60)	**Households in hall Kigali city(309,947)**	**Urban Households use Nduba dumpsite (235,560)**
Municipal Solids waste for 4 weeks (24)(Kg)	4191.765	21,653,749.77	16,456,869.39
Municipal Solids waste per day (Kg)	174.657	902,239.57	685,702.89

Municipal Solids waste generated daily is about 174.657 kg for 60 households. According to (NISR, 2015) the households in Kigali city have a much higher average consumption than those in other provinces. The number of household in Kigali city is about 309,947 households where the total households in urban areas (using Nduba dump site for waste disposal) is about 76% (NISR, 2015); corresponding to 235,560 households. However, the daily Municipal Solids waste generated in Kigali city is about 685,702.89 kg.

As shown in Figure 4.1, the percentages of the individual waste component in the entire waste stream in AGATARE cell were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, biodegradable organic waste and others waste respectively. The figure shows that almost all waste generated in Umucyo village is organic and those from others (clothes, shoes, bones, hair, Pampers) is the second-largest proportion of material in Umucyo village. Comparing the composition of wastes generated, it is shown that the organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate.

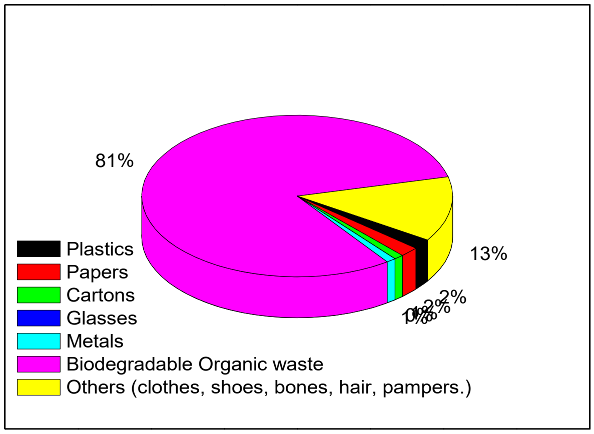

Figure 7: Percentage of the individual waste component in the entire waste stream; Umucyo village-Agatare cell

Figure 7 shows that Agatare cell-Umurava village- generates a high rate of organic waste at 73% while the other components are generated at a very low rate. 1%, 1%, 1%, 1%, 1%, 73%, 22% for plastics, papers, cartons, glasses, metal, Biodegradable organic waste and others waste respectively. The figure shows that almost all the waste generated from Umurava village is organic. Waste from others (clothes, shoes, bones, hair, Pampers) is the second-largest proportion of material in Umurava village. Comparing the composition of wastes generated, it is shown that organic waste has higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate.

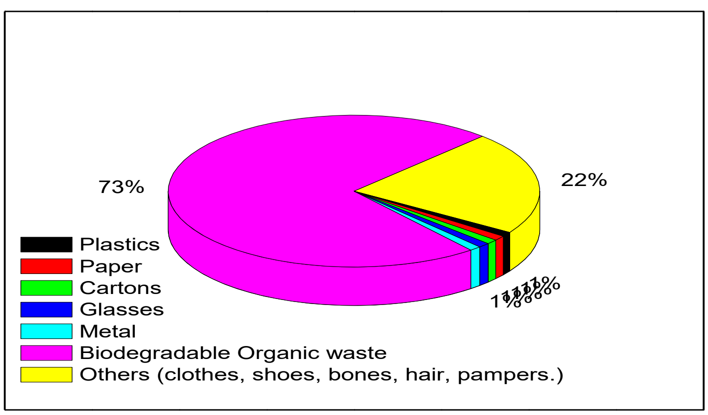

Figure 8: Percentages of the individual waste component in the entire waste stream in Agatare cell- Umurava village.

As shown in Figure 8, the percentages of the individual waste component in the entire waste stream in BIRYOGO cell were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, biodegradable organic waste, and others waste respectively. The figure shows that almost all waste generated from Biryogo is organic waste and those from others (clothes, shoes, bones, hair, Pampers) make the second largest proportion of material in Biryogo village.

Comparing the composition of wastes generated, it is shown that organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate

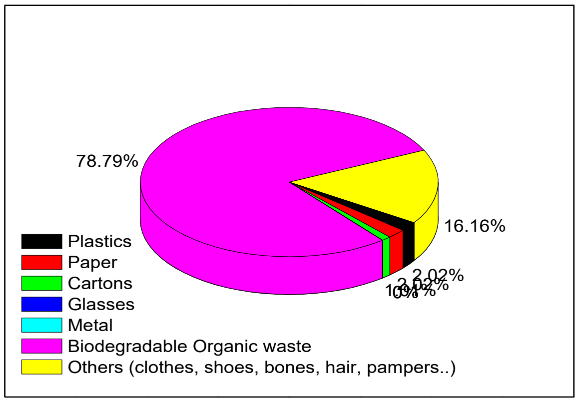

Figure 9: Percentages of the individual waste component in the entire waste stream in Biryogo cell-Biryogo village

As shown in Figure 9 the percentages of the individual waste component in the entire waste stream in BIRYOGO village were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, biodegradable organic waste, and others waste respectively. The figure shows that almost all waste generated from Umurimo village is organic waste and those from others (clothes, shoes, bones, hair, Pampers) make the second largest proportion of material in Umurimo village. Comparing the composition of wastes generated show that organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate.

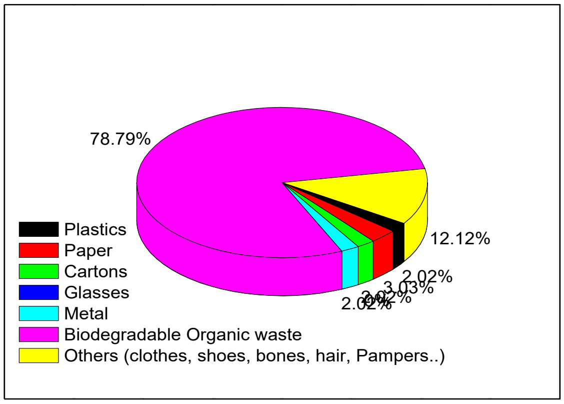

Figure 10: Percentages of the individual waste component in the entire waste stream in Biryogo cell-Umurimo village.

As shown in Figure 10 the percentages of the individual waste component in the entire waste stream in KIYOVU cell were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, Biodegradable organic waste, and others waste respectively. The figure shows that almost of all Ganza village waste generated is organic waste and those others(clothes, shoes, bones, hair, Pampers) is the second-largest proportion of material in Ganza village. Comparing the composition of wastes generated, it is shown that organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate.

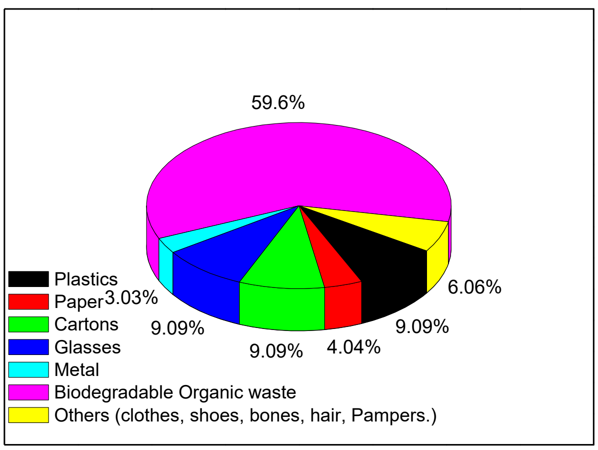

Figure 11: Percentages of the individual waste component in the entire waste stream in Kiyovu cell-Ganza village.

As shown in Figure 11 the percentages of the individual waste component in the entire waste stream in KIYOVU cell-Muhabura village were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, Biodegradable organic waste, and others waste respectively. The figure shows that almost all waste generated from Muhabura village is organic waste and those from others (clothes, shoes, bones, hair, Pampers) make the second largest proportion. Comparing the composition of wastes generated show that organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a high rate

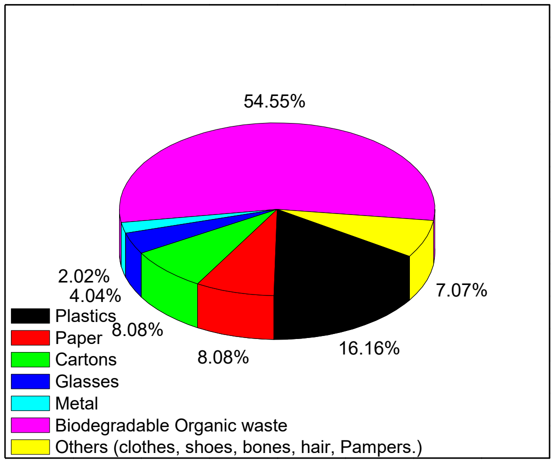

Figure 12: Percentages of the individual waste component in the entire waste stream in KIYOVU cell-Muhabura village.

As shown in Figure 12, the percentages of individual waste component in the entire waste stream in AGATARE, BIRYOGO, KIYOVU cells were 2%, 2%, 1%, 0%, 1%, 81%, 13% for plastics, papers, cartons, glasses, metal, biodegradable organic waste and others waste respectively. The figure shows that almost all the waste generated is organic and those from others (clothes, shoes, bones, hair, Pampers) are the second-largest proportion of material in the surveyed area. Comparing the composition of wastes generated, it is shown that organic waste has a higher rate than the other components. These differences reflect the biodegradable waste produced in the residential house at a higher rate.

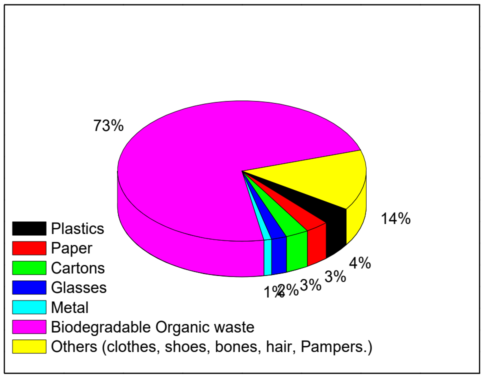

Figure 13: Percentages of the individual waste component in the entire waste stream in AGATARE, BIRYOGO, KIYOVU cell.

4.2 Chemical Characteristics Of Organic Fraction Of Municipal Solid Waste

Table 4.2.1: Summary of the MSW characteristics over a period of 24 weeks.

Percentage dry matter (%D_M)	Volatile solids (gVS/kg $_{DM}$)	Chemical oxygen demand (gCOD/kg $_{DM}$)	Biochemical oxygen demand (gBOD/Kg. $_{DM}$)
22.4	910.228	1304.576	597.714

From the data on MSW characterization over a period of 24 weeks, the mean values for the physical-chemical characteristics of DM, VS, COD, and BOD obtained were 22.4, 910.228gVS/kg_{DM}, 1328.262gCOD/kg_{DM} and 597.714gBOD/kg respectively.

A dry matter content of 22.4 % agrees with other figures obtained by researchers working in this field. (Brummeler et al., 1992) obtained a value of 36% for the source-separated organic fraction of MSW consisting of mainly vegetable, fruit, and yard trimmings. (Wellinger, A., Baserga, U. & Egger, 1992), have reported that dry matter content of source-separated MSW with composition as described ranges from 18% to 30%.

The dry matter content may be taken as an estimate of the chemical oxygen demand since a kilogram of dry MSW contains about 1.305kg COD. The volatile solids content was found to be lower than the COD. Possibly, this was because of the loss of alcohols and acetic acids which may have volatilized during the heating process.

The value for BOD_5^{20} was found to be 597.714g BOD/kg for Municipal waste. From (Hur *et al.*, 2010), BOD /COD ratios ranged from 0.26 to 0.77 for the non-urban areas whereas the urban areas exhibited much smaller range from 0.32 to 0.58, therefore, a value of 0.458 rations for BOD /COD ratio is acceptable.

4.2.1 Chemical characteristics of digester Slurry

Table 15: Summary of the Anaerobic Digester Slurry Characteristics.

	Percentage dry matter (%DM)	Volatile solids (gVS/kg_{DM})	Chemical oxygen demand ($gCOD/kg_{DM}$)	Biochemical oxygen demand ($gBOD/Kg_{DM}$)
D1	10.5	647.72	890.4	303.959
D2	12	605.334	700.48	246.893
D3	10	637.478	672	216.716
mean	10.5	630.177	754.293	255.856

From the data on Anaerobic Digester Slurry characterization over a period of 24 weeks, the values for the physical-chemical characteristics of DM, VS, COD, and BOD obtained were 10.5, 630.177gVS/kg_{DM}, 754.293$gCOD/kg_{DM}$ and 255.856gBOD/kg respectively. The data shows that the total solids was about 10.5%,implying that anaerobic digestion of MSW at low solids was carried at 10.5%TS. (Phale, 2005) has given the range at which low solids anaerobic digestion can take place as 8%TS to 12%TS. The volatile solids, biological oxygen demand, and the chemical oxygen demand give an indication about the active biomass in the sludge.

4.2.2 Lab-scale anaerobic digestion of MSW

Anaerobic digestion of MSW low solids at room temperature was investigated using an experimental set-up of a batch anaerobic digester. The digester was started by loading it with low loading rates, comprising kitchen waste which includes food remains, and they were applied as batch loads once a day. The procedure was repeated for 10 days. After about 10 days, the loading rate was stepped up by 1gCOD/L.d, and the procedure repeated until the onset of digester failure. The retention time was taken as 30 days.

Biochemical degradation of MSW resulted in biogas production with main components as methane (CH_4), carbon dioxide (CO_2), and a trace amount of hydrogen (H_2), nitrogen (N_2) and hydrogen sulfide (H_2S).

At each loading rate, the process was monitored using the percentage methane, and methane production rate. The extent of anaerobic digestion was assessed by analyzing the digested slurry for TS, VS, COD, and BOD. Graphs shown in Figure 4.2.3.1, 4.2.3.2 and 4.2.3.3 represent the performance of the low solids anaerobic digester at a specific loading rate as indicated by variation of methane production rate against time.

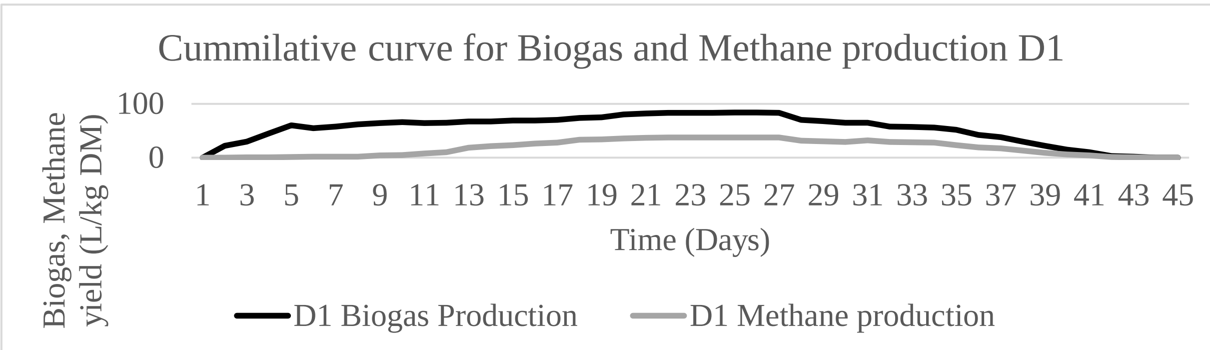

Figure 14: Methane production rate against time for Digester 1

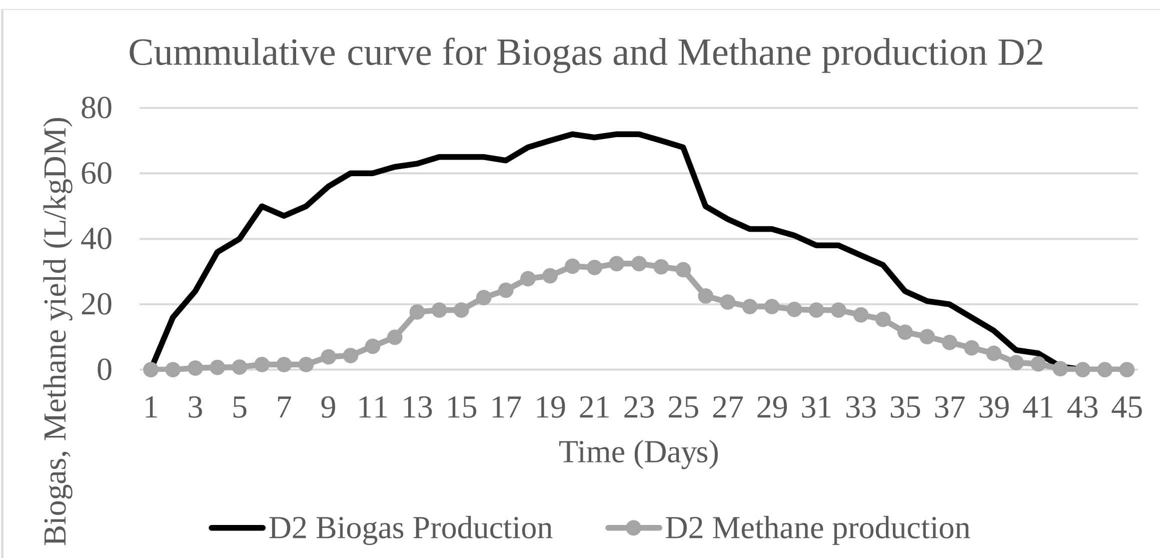

Figure 15: Methane production rate against time for Digester 2

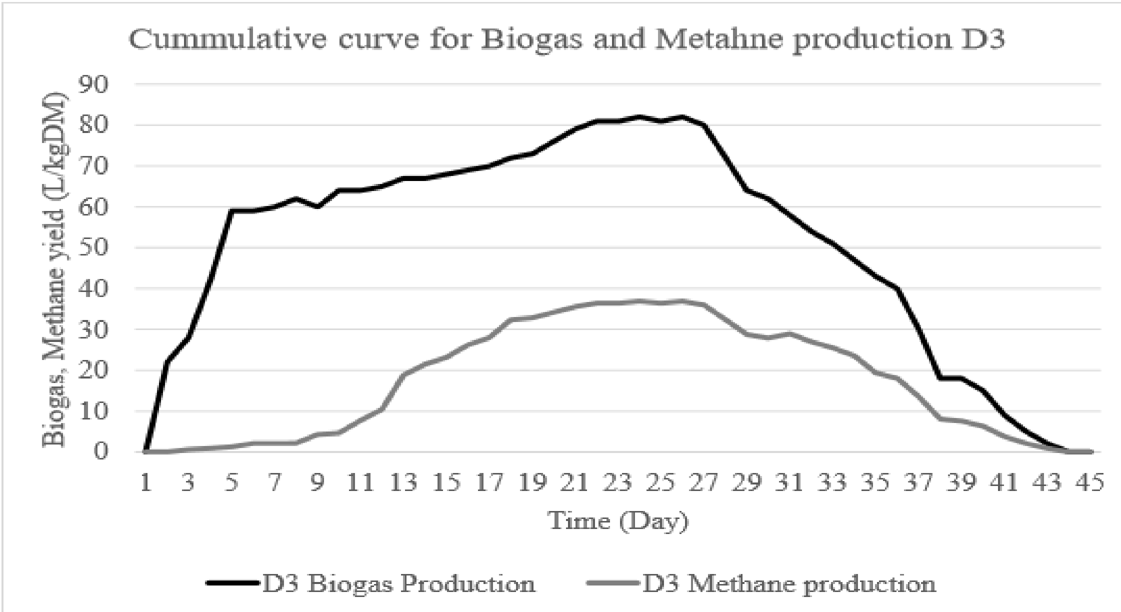

Figure 16: Methane production rate against time for Digester 3

4.3 Discussion of experimental results

4.3.1 Anaerobic digestion

The curves show the produced quantity of biogas and have a maximum cumulative production of about 84 L/kg $_{DM}$ for digester1, 72L/kg $_{DM,}$ for digester 2 and 82L/kg $_{DM}$ for digester 3 while the maximum cumulative volume of methane produced was observed to be about 37.8 L/kg DM, 32.4 L/kg DM and 36.9 L/kg DM respectively.

Methane content for the tree digester represents about 45%, 42% and 45% of the total dry biogas obtained.

From the graphs of figures 4.2.2.1, 4.2.2.2, and 4.2.2.3, it shows that the biogas is produced at a high rate and increased day by day for the first 26th days. Then, it starts dropping after that time for digester one. For digester two, this happened at the 24th day, and for digester three on the 27th day. It was seen that digester one is the one which produces a high rate of biogas. This may be due to its position against the window because the light easily raises the temperature of the digester one. Besides, in the beginning, the digesters were not producing methane as well as biogas. This was probably due to methanogens weakness at the beginning.

The results from the three digesters indicated that the anaerobic digester produces a low volume of biogas and methane as the methane content does not lie within the range 50-60% of biogas production. In addition, other than methane, the other components of the biogas were CO2 (40%) and O2 (14%) and H2S 98 particle per million (98 ppm).

The reasons for low biogas production from the digester can be characterized as following:

The temperature: While conducting the experiment, sometimes, the temperature dropped down to 14^0 due to the season. Most of the time, the temperature was below what is required, so the anaerobic digestion could not be performed under required temperatures.

Types of microbial degradation capability: The fact used for opening and closing has increased the oxygen in the digester as the elevation of oxygen concentrations affects the growth properties and metabolism of bacteria in a bioreactor that deactivate the production of bacterial.

Mixing techniques: These are thought to optimize the process of anaerobic digestion by enhancing interaction between cells and substrates and removing the inhibitory metabolic products from the cells (Chynoweth D.P, 1996), (Maniatis *et al.*, 1987)(Chynoweth and pullammanappallil, 1996; Megaert and Verstraete, 1987). PH tended to dip below 6.5. For pH values outside the range, 6.5 - 7.5, the rate of methane production is lower (T.Z.D. de Mes, A.J.M. Stams, 2003).

4.4 Design Consideration

From the survey done in Kigali city, it was seen that the daily municipal solid waste generated in Kigali city is about 686,000 kg out of which, the organic waste proportion is high. The organic waste materials are the most generated at a rate of 73% which corresponds to 500,000 kg. This is shown in table 3.8. The dry matter content for this fraction of MSW is about 22.4% and corresponds to 112500 kg. The fraction of organic matter can be gathered and used as raw material for industrial-size anaerobic digestion for the production of biogas, which will generate green electricity and compost as the end products and consequently, reduce the amounts of MSW destined for the dumpsite.

The optimization of anaerobic digestion of MSW and other substrates is dependent upon understanding the microbial mechanisms involved and the application of this knowledge for improved design, operation performance evaluation, and control.

Anaerobic digestion of MSW has been investigated in the laboratory. In Table 3.8, the results obtained as well as those calculated based on the data are listed in this table below.

Table 16: Chemical, Biological characteristics of MSW

Percentage of dry matter (%DM)	Volatile solids (gVS/kg DM)	Chemical oxygen demand (gCOD/kg DM)	Biochemical oxygen demand (gBOD/Kg DM)
22.4	910.227	1304.576	597.714

4.5 Methane generated in terms of dry matter

From studies done in the laboratory, one kg of dry matter produces 1.305 kg of COD. At normal conditions, 273.15K (0^o) and 1.013 bars (atmospheric pressure), the methane produced from 1 g of dry matter equals to 0.457 LCH4 from the equation 3 in Literature review (1 Kg COD ~ 0.35 m3 CH4and (1kg DM = 457 LCH4)**.** From the laboratory test, it was seen that the dry matter content is 22.4% of Municipal waste. Therefore, Kigali City will produce 51,384,375 L of methane as it generates 112500 kg of dry matter.

4.6 The energy content of biogas

Typical normal cubic methane [volume under normal conditions, 273.15 K (0 o) and 1.013 bar (atmospheric pressure)] has a calorific value of about 10 kWh, while carbon dioxide is zero. Therefore, the energy content of biogas is directly related to the methane concentration. In other words, a biogas composition with 50% methane is assumed, in which case the energy content will be about 5.0 kWh per normal cubic meter. Therefore, normal cubic meter for natural gas is assumed 11 kWh energy content (Swedish gas center, 2012). The methane produced from the MSW generated from Kigali city will contain 565,228 KWh.

4.7 Electricity generation

Biogas can be used in various ways, including heat. The gas is burned in the boiler and the heat generated warms water. It can be used to replace nearby buildings or a local district heating network. Gas boiler acts as a hard and fluid fuel boiler, but the difference is that the boiler gases are specifically modified. In addition, the station engine fuel can generally be used as biogas, usually an auto or diesel engine or a gas turbine.

Electricity is generated from biogas by combustion of gas engine or turbine. Use auto and diesel engines.

About one-third of the energy is used for power generation, and two-thirds of the energy is converted into heat. About 30-40% of the energy is used for power generation and remaining energy becomes heat. By taking 32% of the energy used for power generation, the estimated power generation in Kigali city will be 180,873 kWh of electricity for every day.

4.8 Sizing anaerobic digester for municipal solids waste in Kigali City

4.8.1 Size specification

The specification of the anaerobic digester of the high content of solids on a large scale was based on the values obtained from the exercises of quantification and characterization of waste. The appropriate input parameters were determined as the volumetric flow of the raw material that helped the design of the bioreactor using the following formulas.

Vr: volume of the reactor

Vg: Volume of gas the holder

Vd: Volume of the bio-digester

Q: Volumetric rate

HRT: Hydraulic Retention Time of the feedstock in days

OLR: Organic Loading Rate

Assume the volume of the gasholder to be the half of the reactor Vg=Vr /2

Vd=Vr+Vr/2=3Vr/2

4.8.1.1 Digester model selection and dimensioning

Based on the standard sizes of the selected digester model with geometric formulae, the appropriate dimension of the digester was determined.

- The reactor with a cylindrical tank of the volume(Vr)

  As Vr =

  Where D is the diameter of the tank and

  H is the height of the tank

  Assume D=H Hence Vr =

  Hence the diameter D can be given as

  D=

Taking the gasholder/digester radial clearance to be 300mm, gives a diameter (d) of the gas holder as d= (D-0.6) =)-0.6

Given a gasholder volume (Vg), the height (h) of the gasholder is therefore for being given by:

$h=*(()-0.6)^{-2}$

4.8.1.2 Feedstock characteristics

Table 17: Feedstock characteristics

Parameters	Values
The average daily generation rate	500,000
Total solids	22.4%
Moisture content	77.6%
Volatile solids(VS)(%TS)	91.02%
Fixed Solids(FS)(%TS)	8.98%
Density	775.0kg/m^3 (Kigozi, Aboyade and Muzenda, 2014)

Table 5.2. An average of 500,000 kilograms of biodegradable waste is produced per day, of which 22.4% is solids and the remaining 77.6% is all water. Further, in the solid, 91.02% is a digestible component, and the remaining 8.98% is ash. In general, the OMSW features obtained are consistent with most of the review literature; (Kigozi, Aboyade and Muzenda, 2014) indicated that typical OMSW have TS and VS ranges of 20-30% and 90-95%, respectively.

4.8.1.3 Plant size

3.1.1.1.1. Bioreactor size

Q=500,000 kg/775.0kg/m3=645 m^3/day

To achieve substrate fluidity, the feedstock is mixed with water at a ratio of 1:1. Hence, additional 645$m^3$of water is to be added, giving a total feedstock flow rate of the approximately 1290-m3per day.

From Literature, HRT is in the range of 21-30, take the maximum HRT 30 days

Vr=1291.606m3/day*30 days=38,710 m^3

OLR for OMSW range between 5-10kgVs/m^3

OLR= (Q*S)/Vr

S=Concentration of Volatile Solids in the input (kg/m^3)

S=TS*VS*Density

S=0.224*0.9102*775=158 kg/m3

OLR=1291.606*158.0107/38748.193=5.267kgVS/m^3

It is seen that Organic loading rate is within the range 5-10 means 38,710 m^3 reactor size is meeting the standard.

2. Gas holder Size

Vg=Vr/2=38,710 m^3/2=19355 m^3

Vd = Vg+Vr = 58,065 m^3

D= =36.67m

H=D

d=D-0.6=36.07m

h==18.65m

Table 18: Bio digesters dimensions

Vr(m^3)	Vg(m^3)	Vd(m^3)	H(m)	h(m)	D(m)	d(m)
38710	19355	58065	36.67	18.65	36.67	36.07

3.1.1.1.2. Digester model selection and dimension

The selected digester is commercial Biogas digester with a cylindrical design and vertical classification design. The digester consists of vertical concrete or steel digesters with rotating propellers or immersion pumps for homogenization that is widespread. This was chosen because is simpler and cheaper to operate, but the feedstock may not reside in the digester for the optimum period. The digester will be built underground.

4.9 Costs and benefits analysis

4.9.1 Investment cost

The investment cost is undoubtedly the most significant in the process of energy recovery from MSW by use of anaerobic digestion. It is related to the quantity and description of materials required for the construction of complete high solids anaerobic digester.

Table 19: The quantity and description of materials

Materials	Quantity	Unity
Rebar	177	Ton
Cement	1573.531	Ton
Sand	1966.913	m^3
Gravels	3933.827	m^3

In construction, there are different steps and works undertaken for accomplishing the project. The required works and steps in the construction of the commercial anaerobic digestion plan are the following:

4.9.1.1 Facility layout

The facility layout includes the selection of a single-stage biogas facility with a long track record, low capital costs and technical issues, and digestion in two levels of biogas facilities in two different tanks to optimize operating conditions.

4.9.1.2 Dimension making

Dimensional markings are considered to be preparation for excavation and construction. The width of 3 meters around the digestive pond should be considered. In order to prepare the structure of the concrete foundation, workers must implement the construction work around the tank base and use this area.

4.9.1.3 Excavation works

The depth of the excavation depends on the specifications of the soil. Tilted on both sides. For viscous soils, the depth should be 30 cm per meter and for light, 60 cm to 1 m.
The soil and sand are 90 cm.

4.9.1.4 Preparation of the digester's bottom

The bottom uses water: cement ratio (0.53 L kg-1), cement: sand: gravel mass ratio (1:2.2:3.7) and pre-selected iron rod type is 6Ø6m-1 or 6Ø8m-1. The thickness of the concrete foundation is between 10 and 25 cm, depending on the soil size and groundwater level.

4.9.1.5 Building the digester

Commercial biogas plants are large in scale and have a diameter of 36.68 meters. Therefore, concrete structures should be reinforced. Iron bars were used to construct two iron meshes to strengthen the digester wall from the bottom of the digester. The standard length of iron bars is 12 meters.

4.9.1.6 Integrating the heating tubes

The heating tube should be integrated into the wall structure to form an iron grid that will be wrapped by wood or prefabricated metal sheets. The heating tubes are made of polyvinyl chloride (PVC) before the concrete is poured, and the hot water flows in these tubes to heat the digester. The water temperature is 35 ° C or 55 ° C, depending on the bacteria used, mesophilic bacteria or thermophilic bacteria

4.9.1.7 Building the gas holder

A wooden or steel structure in the form of an umbrella is constructed, and the mesh network is then relayed onto the umbrella structure. An air bearing dual membrane cover including a gas retainer is mounted to the structure. A flexible membrane for a gas collector.

4.9.1.8 Technology installation

Techniques to be installed include filling indicators, tubes, measuring devices and meters, power grids, fiber optic cables, mixers, etc. A gas collector and excess and low-pressure protection and air support fans should then be installed.

4.9.1.9 Installing the insulation

This is the process of lining the digester with a mortar or foam sheet. This is one of the most important construction steps and should be implemented carefully and accurately. In the case of a lining, the process is carried out using a mortar containing 1% silica. After the lining is completed, the digester is applied with petroleum protein. The description and quantities of materials and their prices which are required for construction of the digester are given below.

Table 20: Inventory of materials and their price estimates

Materials	Quantity	Units	Unit Price $	Total Price
Rebar	177	ton	365	64605
Sand	6970.63	m^3	0.8	5577
Gravels	3933.827	m^3	20	78676.54
Cement	1573.531	Ton	4250	7474272
Bulldozer	6970.63	m^3	0.8	5577
Pre-constructed metal sheets: to protect the internal face of the wall against corrosion.	1/3 of Vd: 1408.2	m^2	150	71075
Cement: sand	1:4	kg	done	
Heating tubes: Hot tub heater	232489.158	pc	60	13949349
Miscellaneous: The filling indicator, tubes, measuring devices and meters, electricity network, fiber cables, wedding rods, mixing…	N/A	N/A	N/A	5000
Biogas electricity generator Sunsungs10-1000	3	pc	10000	30000
sheets of foam for the insulation	4224.6	m^2	3.6	5109
Painting the insulation using the petroleum Albumen	4224.6	m^2	59/barrel	210
			Total $	110,316,034.5

At 50% labor cost, the overall cost of for a 58065 m^3 high solids anaerobic digester is estimated at 89,924,777,426 Rwf for a payback period of 10 years at a compound interest of 15% p.a., the annual payment amount to 22,481,194,357 Rwf.

4.9.2 Maintenance and operation costs

A biogas plant with an annual production capacity of 500,000 tons per day requires 5-9 hours of work per day to keep workloads to a minimum by specifically recommending effective control technology measurements. In order to exchange data securely, the person who is not on-site can also monitor and control the unit, i.e. the unit can be controlled remotely. For example, the agitator can be turned on and off and all solids supply equipment can be monitored. Information about the fault can be registered on the computer service or on the operator's mobile phone, which ensures a short response time in the event of any unexpected situation.

The plant produces 180,873 kWh of electricity per day with 500.000 tons of biomass. It will be needed minimum maintenance costs to run several years for the optimal gas processing engines. Up to 30% of the waste heat from the water that cools the engine is used in heat exchangers and fomenters, so no additional heat is needed and the remaining heat can be advantageously used to heat plants and houses. The electricity generated by combined heat and power (CHP) is converted to high voltage, which can then be fed into the grid to meet the annual demand of approximately 309,947 households.

4.10 Benefits

4.10.1 Benefits from the biogas energy generated in Kigali City

The cost of electricity supply from hydropower will be reduced while using the electricity produced from gas methane. The electricity produced from the Biomass is less costly than that produced by hydropower. This can be shown by calculations, the income in Kshs. As electricity cost is equivalent to 20Ksh/KWh, it will be 3617460 Kshs. Equivalent to 28939680 Rwf per hour, and Annual savings from the municipal solids waste of Kigali can be 2.54206E+11Rwf.

With the study of Green Economy Sectorial on the energy –RWANDA, biomass contributes 86% to Rwanda's main energy supply. Electricity supply is still very low. In 2010, electricity consumption per capita was 26.5 kWh per person. From the municipal solids waste, the population of Kigali will benefit the electricity from biogas and the rate of the population access the electricity will be increased, as the electricity will be increased about 18% kWh/person.

Currently, only 6 percent of the households have access to energy. This rate is very low as it can be raised up by producing the electricity from municipal solids waste. The country has currently 243000KWh, andthe organic solid waste generated from Kigali City may produce 180873KWh, which is 56% of the daily demand in Rwanda. The percentage of electricity per household will be increased as the electricity will be increased. Kigali alone accounts for nearly two thirds of total electricity consumption in the country. Based on annual electricity energy requirement for Kigali City per person, the benefits of using biogas can be calculated as the increase in electrical energy gained from biogas.

5 RECOMMENDATION AND CONCLUSION

5.1 Conclusion

The research was conducted in order to evaluate the feasibility of anaerobic digestion in producing the biogas from municipal organic waste in Kigali city. The discussion of the above results highlights the possibility of reusing biogas as a means of promoting green energy from waste. Nonetheless, the result from the laboratory experiment indicated that the setup had produced a lower rate of methane and biogas. However, from laboratory tests, the results showed that this kind of bio-waste should produce the required biogas; the reasons for failure were determined in laboratory experimental discussion.

From the survey done in Kigali city, it was shown that organic waste is more generated. It yields 73% rate with (500,000 kg) of total municipal waste. This implies that while managing the organic waste by producing the biogas, the population of Kigali city will benefit from it. Although the possibility of managing solid waste in Kigali is relatively large, the management of organic solid waste requires advanced planning to facilitate the operation of biogas production.

The results show that organic waste in Kigali can reduce 457 L / kg DM methane. When calculating the methane and power generation potential, consider the 457L / kg DM value. The total evaluation value of methane is 51,384,375L, and the electricity from derived methane was 180,873KWh, which is 56% of the daily demand in Kigali City. The quantity of municipal waste generated in Kigali City was used for designing the biodigester required. The volume of the biodigester was found to be 58,065m3. Based on the energy recovered, a cost-benefit was done and revealed that Kigali city will benefit this project as the population accessing the electricity will be increasing, but for now, it is still low.

5.2 Recommendation

The digester set-up was found to be producing a low rate of methane than that it should be producing. So, further research in this area is recommended:

1. In order to empower the set up to produce a sufficiency rate.
2. In the direction of improving anaerobic digestion set-up condition.
3. In order to improve mixing techniques to optimize the process of anaerobic digestion by enhancing interaction between cells and substrates.

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7 ANNEXES

7.1 Definition

Biodegradable waste: is defined as any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste, and paper and cardboard.

Commercial waste: means waste from premises used wholly or mainly for the purposes of a trade or business, or the purposes of sport, recreation, or entertainment.

Controlled waste: refers to the household, commercial and industrial waste, or any such waste, as defined in the Waste and Contaminated Land (NI) 1997. Such wastes are subject to the control of the relevant authority and require a waste management license for their disposal.

Household waste: means waste arising from a domestic property, caravan, residential home, premises forming part of an educational establishment, and premises forming part of a hospital or nursing home.

Industrial waste: means waste from a factory, and any premises used for the purposes or provision of public transport, postal and telecommunications services, and utilities.

Municipal waste: is defined as household waste, and any other waste under the control of (ie collected by) District Councils, or their agents, acting on their behalf.

Sewage sludge: These are the solids captured and semisolids residuals generated by the treatment of commercial and domestic sewage at wastewater treatment works.

Waste: is defined as any substance or object which the producer or the person in possession of it, discards, or intends to discard.

Anaerobic digestion: a biological process that involves the breakdown of organic material by bacteria in the absence of oxygen. It produces a biogas that can be used to produce energy and a digestate.

Composting is the controlled biological decomposition of biodegradable materials (e.g. garden waste or sewage sludge) under aerobic conditions in order to produce compost, which can be used, subject to quality standards, as a fertilizer or soil improver.

Energy from waste: thermal or biological processes that recover the energy from waste materials to produce power and heat. It includes thermal treatment processes: incineration, and gasification and pyrolysis; as well as anaerobic digestion

Landfilling: the disposal of waste by its permanent deposition in or on the ground.

Materials Recovery Facility (MRF): a facility at which materials, for example, paper, metals, and/or plastics are separated manually or mechanically, from mixed waste streams, and baled and stored for reprocessing.

Recovery: The recovery of energy or materials, and includes recycling, composting and energy from waste.

Recycling is the collection or recovery of re-useable materials from the waste stream and the subsequent processing of those materials into usable products

Reuse: The re-use of waste items, for example, bottles or packaging.

Treatment is the physical, thermal, chemical or biological processes, including sorting, that change the characteristics of the waste, in order to reduce its volume or hazardous nature, facilitate its handling, or enhance recovery.

Waste Minimization: is the way of reducing the quantity of waste generated which requires treatment and /Or disposal

Sector- Is part of a District which part of a city, say Kigali.

Cell- This is a part of a sector as defined above.

7.2 Field work Activities







7.3 Field work data

Cell	Agatare																				
Village	UMUCYO																				
	QUANTITY (in Kg)																				
WASTE TYPE	H1				H2				H3				H4				H5				
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	
plastics	1.30	0.50	0.70	0.00	1.00	0.30	0.10	0.10	0.80	0.50	0.30	0.10	0.80	0.20	0.30	0.00	0.50	0.70	0.20	0.10	
paper	0.50	0.10	0.10	0.20	1.00	0.60	0.90	0.30	0.50	0.30	0.10	0.20	0.70	0.40	0.30	0.10	1.00	0.50	0.40	0.10	
cartons	0.50	0.10	0.20	0.00	0.50	0.30	0.10	0.00	0.50	0.10	0.20	0.30	0.60	0.20	0.00	0.10	0.40	0.00	0.00	0.00	
glasses	1.30	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.20	0.00	0.00	0.10	0.30	0.00	0.00	0.20	
metals	1.50	0.40	0.60	0.10	0.20	0.00	0.00	0.10	0.00	0.30	0.00	0.12	0.30	0.10	0.10	0.00	0.20	0.30	0.40	0.00	
organics	37.50	35.00	24.00	25.00	25.00	23.00	17.00	13.00	24.00	19.00	17.40	15.00	4.00	5.00	6.00	4.50	13.00	11.00	4.00	7.50	
others	1.50	6.00	5.00	1.50	1.00	1.60	1.30	1.90	6.00	4.50	5.30	3.20	3.00	4.30	4.00	5.00	4.00	3.00	0.50	0.70	

UMUCYO																			
QUANTITY(In kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
0.10	0.50	0.40	0.40	0.40	0.50	0.30	0.00	0.30	0.40	0.20	0.00	0.10	0.30	0.30	0.20	0.30	0.30	0.40	0.20
0.30	0.10	0.30	0.70	0.70	0.20	0.10	0.10	0.50	0.30	0.10	0.20	0.60	0.50	0.30	0.20	0.40	0.10	0.30	0.10
0.20	0.00	0.00	0.30	0.30	0.40	0.00	0.40	0.20	0.40	0.00	0.50	0.30	0.40	0.20	0.20	0.40	0.30	0.00	0.20
0.00	0.00	0.10	0.00	0.30	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00	0.30	0.00	0.10	0.00
0.00	0.20	0.10	0.00	0.20	0.00	0.20	0.00	0.50	0.00	0.10	0.10	0.30	0.00	0.20	0.00	0.50	0.60	0.20	0.00
11.00	12.30	7.00	12.00	20.00	21.00	8.30	6.25	10.00	8.50	6.20	5.00	30.00	20.00	25.00	22.90	29.00	27.00	8.50	14.00
0.50	0.90	1.50	0.80	2.50	1.60	1.00	1.60	5.00	6.00	2.90	1.00	1.00	0.40	0.50	0.60	4.50	3.80	1.00	2.50

UMURAVA																			
QUANTITY (In Kg)																			
H1				H2				H3				H4				H5			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
0.50	0.20	0.50	0.30	0.00	0.10	0.30	0.20	0.20	0.00	0.10	0.20	0.30	0.20	0.20	0.10	0.00	0.20	0.20	0.20
1.00	0.10	0.20	0.10	0.00	2.00	0.30	0.10	0.10	0.10	0.20	0.10	0.00	0.10	0.10	0.00	0.00	0.20	0.20	0.10
2.50	0.50	0.20	0.20	0.50	0.30	0.10	0.10	0.40	0.20	0.00	0.10	0.30	0.10	0.10	0.10	0.20	0.10	0.10	0.10
4.00	1.00	0.20	0.00	0.00	0.00	0.20	2.00	0.00	0.00	0.20	0.30	0.00	0.00	0.00	0.00	0.50	0.10	1.00	0.50
0.50	2.00	0.20	0.20	0.30	0.00	0.10	0.00	0.00	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.20	0.50	0.20
23.00	36.00	32.00	30.00	18.00	10.00	21.00	16.00	21.50	15.00	22.00	6.00	27.00	23.00	20.00	13.00	19.50	26.00	23.00	16.00
25.00	21.00	27.00	22.00	0.00	2.00	3.00	5.00	2.00	1.30	5.00	9.00	1.50	10.00	6.00	2.00	1.50	5.00	7.00	7.00

UMURAVA																			
QUANTITY(in kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
0.00	0.10	0.10	0.20	0.30	0.10	0.20	0.10	1.00	0.20	0.10	0.20	0.50	0.80	0.20	0.20	0.00	0.50	0.20	0.20
0.00	0.20	0.10	0.10	0.00	0.20	0.10	0.10	0.10	0.00	0.10	0.10	0.10	0.10	0.20	0.10	0.00	2.00	0.10	0.10
0.30	0.10	0.10	0.20	0.20	0.10	0.00	0.10	0.60	0.20	0.10	0.10	0.90	0.10	0.10	0.10	0.10	0.10	0.10	0.10
0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.50	0.20	0.50	0.00	0.00	0.20	0.10	0.00	0.00	0.40	0.00	0.00
0.00	0.10	0.00	0.10	0.00	1.00	0.20	0.10	0.00	0.10	0.10	0.10	0.00	0.10	0.00	0.00	0.00	0.60	0.10	0.10
11.00	8.50	7.00	10.00	2.00	10.00	5.00	10.50	22.50	21.00	18.00	20.00	11.00	12.50	10.00	12.00	19.50	12.50	4.50	6.50
0.50	0.00	1.50	1.00	1.00	0.00	1.00	0.50	3.00	1.00	4.00	2.00	0.00	4.20	0.50	4.00	3.00	2.00	2.00	0.50

Cell	Biryogo																			
Village	BIRYOGO																			
WASTE TYPE	QUANTITY (in Kg)																			
	H1				H2				H3				H4				H5			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
plastics	2.50	0.60	0.50	0.60	0.50	0.10	0.10	0.20	1.00	0.25	0.30	0.20	0.50	0.20	0.30	0.60	1.00	0.50	0.10	0.10
paper	1.00	2.00	0.30	0.20	0.00	0.00	0.00	0.10	1.50	0.20	0.20	0.30	0.50	0.10	0.60	0.50	0.60	0.60	0.40	0.30
cartons	0.00	1.00	0.60	0.90	0.00	0.00	0.00	0.00	0.00	0.01	0.30	0.00	1.00	0.00	0.10	0.00	0.50	0.50	0.20	0.80
glasses	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
metals	0.00	0.20	0.10	1.03	0.00	0.10	0.01	0.01	0.50	0.01	0.01	0.10	0.00	0.01	0.02	0.01	0.00	0.01	0.01	0.10
organics	12.00	15.00	18.00	25.00	36.00	18.00	9.50	10.00	16.00	22.50	14.50	16.50	25.00	10.50	20.00	25.00	17.00	15.00	14.00	13.00
others	0.00	7.00	8.00	12.50	0.10	1.00	14.00	4.50	7.50	0.50	1.50	4.00	1.00	1.00	4.00	0.20	5.00	5.10	0.40	2.00

BIRYOGO																			
QUANTITY(In kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
0.10	0.10	0.20	0.20	0.60	0.50	0.20	0.80	0.20	0.50	0.40	1.50	0.20	0.10	0.30	0.30	0.50	0.50	0.60	0.20
0.30	0.20	0.30	0.40	3.00	0.60	0.20	1.00	0.30	0.60	0.30	0.90	0.30	0.20	0.20	0.20	1.50	0.60	0.40	0.30
1.00	0.00	0.10	0.00	0.40	0.00	0.80	0.40	0.40	0.30	0.20	0.00	0.00	0.00	0.80	0.80	0.00	0.00	0.60	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.01	0.01	0.02	0.00	0.01	0.02	0.10	0.00	0.02	0.02	0.01	0.00	0.00	0.10	0.10	0.00	0.01	0.10	0.00
10.00	8.00	9.50	11.00	16.00	20.00	17.00	22.00	38.00	23.50	15.00	12.00	10.00	2.80	14.00	14.00	10.00	11.00	29.50	15.00
4.60	4.00	10.00	0.90	1.00	2.00	2.50	2.00	2.00	1.40	1.20	1.30	0.00	0.00	0.10	0.10	2.00	3.00	16.00	0.00

UMURIMO																			
QUANTITY (in Kg)																			
H1				H2				H3				H4				H5			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
2.00	0.50	0.40	0.30	0.00	0.50	0.30	0.50	0.60	0.80	0.40	0.30	0.20	0.10	0.20	0.60	0.10	0.10	0.70	0.30
3.00	0.60	0.20	0.50	0.30	0.80	0.40	0.30	0.80	0.60	0.50	0.40	0.10	0.40	2.00	0.50	0.20	0.20	0.20	0.20
0.50	0.00	0.50	1.00	0.20	0.60	1.00	1.00	0.50	1.00	0.60	0.90	0.20	0.20	0.30	1.00	0.00	0.00	0.10	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.40	0.02	0.10	0.20	0.00	0.10	0.01	0.01	0.00	0.02	0.00	0.00	0.00	0.01	0.10	0.00	0.00	0.01	0.01	0.00
30.00	32.00	27.00	27.00	6.00	10.00	15.00	10.00	10.00	16.00	7.00	18.00	10.00	17.00	14.00	10.50	9.00	10.00	10.50	5.00
4.00	3.80	4.00	10.00	0.00	8.00	13.00	1.50	0.00	2.00	1.00	8.00	0.00	0.60	3.00	2.70	0.10	0.30	2.50	0.00

UMURIMO																			
QUANTITY(in kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
0.60	0.40	0.50	0.20	2.30	0.10	0.30	0.80	0.30	0.40	0.20	0.30	1.00	0.10	0.30	0.30	0.40	0.50	0.40	0.10
0.20	0.10	0.10	0.30	2.00	0.20	0.20	1.00	0.20	0.20	0.30	0.30	1.30	0.20	0.40	0.30	0.60	0.60	0.50	0.60
0.00	0.50	0.10	0.00	1.00	0.00	0.60	0.00	0.30	0.60	0.40	1.50	0.10	0.00	0.20	0.00	0.00	0.40	0.10	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
0.10	0.60	0.00	0.00	2.50	0.01	0.02	0.10	0.00	0.02	0.02	0.00	0.00	0.02	0.00	0.10	0.00	0.20	0.01	10.00
13.00	8.50	13.50	7.50	2.50	2.00	7.00	7.00	10.00	29.00	30.00	25.00	20.00	20.00	21.00	18.00	13.00	6.50	16.00	20.00
0.20	0.20	0.20	1.00	1.20	0.00	4.00	0.30	2.00	2.40	8.00	2.00	0.20	0.10	0.50	0.10	0.00	2.50	1.00	0.20

Cell	Kiyovu																			
Village	GANZA																			
WASTE TYPE	QUANTITY(in kg)																			
	H1				H2				H3				H4				H5			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
plastics	1.50	1.00	1.00	1.20	1.00	0.50	1.00	0.30	2.00	1.50	1.50	0.40	1.50	1.00	2.00	0.50	4.00	3.00	0.30	0.00
paper	1.00	0.20	2.00	0.50	0.50	0.20	1.50	0.20	1.00	0.50	0.50	0.20	0.50	0.20	1.00	0.30	5.00	0.20	0.10	0.00
cartons	3.00	0.50	0.50	0.20	1.00	0.40	0.50	0.10	7.00	1.00	0.50	0.00	5.00	0.10	2.00	0.40	2.00	0.50	0.30	0.00
glasses	2.00	0.00	0.00	0.20	5.00	1.00	3.00	0.00	10.00	1.00	0.50	1.00	1.50	0.50	0.00	1.00	2.00	1.00	0.00	0.00
metals	1.00	0.00	0.00	0.00	0.50	1.00	0.00	0.00	0.50	0.00	0.00	0.00	1.50	1.00	0.00	0.00	1.00	1.00	0.00	0.00
organics	10.00	10.00	8.00	9.00	29.00	7.00	1.50	18.00	15.00	8.00	0.00	4.00	4.00	3.00	4.00	4.00	3.00	4.00	4.00	2.50
others	0.00	0.50	0.00	0.00	0.00	0.00	1.50	0.00	0.00	3.00	2.50	1.30	0.00	1.00	1.00	0.40	0.00	1.00	0.00	0.00

GANZA																			
QUANTITY(In kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
1.00	0.20	1.00	1.50	1.00	0.50	0.50	0.30	2.00	1.00	0.50	0.30	1.00	0.50	0.40	0.20	2.00	1.50	0.70	1.50
0.50	0.00	0.50	0.50	0.00	0.10	0.20	0.20	0.50	0.20	0.30	0.10	0.00	0.00	0.20	0.00	0.00	0.00	0.20	0.30
0.00	0.20	1.70	0.30	6.00	0.30	0.20	0.50	1.00	0.50	0.20	0.50	2.00	0.00	0.20	0.20	2.00	1.00	0.30	0.40
0.00	1.00	2.00	1.50	0.00	0.50	0.00	0.50	0.00	1.00	0.00	0.00	0.00	0.20	0.50	1.00	1.00	0.30	1.00	1.00
0.00	0.00	0.00	0.00	0.00	0.30	0.50	0.40	0.00	0.50	0.00	0.70	1.50	1.00	0.00	0.00	0.00	1.00	0.00	0.00
1.00	1.00	7.00	9.00	2.00	1.00	5.00	3.00	4.00	3.00	22.00	11.00	2.00	15.00	1.50	3.00	6.00	3.00	15.00	13.00
0.00	1.50	1.00	0.00	0.00	1.00	0.30	1.50	0.00	1.00	0.20	0.00	0.00	2.00	6.00	1.00	0.00	2.00	0.00	0.00

MUHABURA																			
QUANTITY (in Kg)																			
H1				H2				H3				H4				H5			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
1.50	0.30	1.00	2.00	0.00	2.00	1.00	2.00	2.00	0.50	2.00	0.50	0.50	1.00	0.50	1.00	1.00	1.00	0.00	0.00
2.00	1.00	3.00	1.50	0.00	1.00	2.00	1.00	1.00	0.50	0.50	1.00	0.50	1.00	1.00	2.00	0.50	0.00	0.00	0.00
1.20	0.10	1.00	0.50	1.00	4.00	3.00	0.50	0.00	1.00	1.00	0.50	1.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00
0.50	0.02	1.00	0.50	2.00	0.00	1.00	0.50	2.50	0.00	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00
1.00	0.00	0.00	0.50	0.00	1.00	0.50	1.00	0.50	0.00	0.00	0.00	0.00	0.50	0.50	0.50	0.00	0.00	0.00	0.00
14.50	12.20	10.00	3.00	2.00	6.00	10.00	15.00	5.00	0.00	3.00	3.00	0.00	0.00	0.00	0.00	18.00	5.00	6.00	5.00
2.00	1.20	1.00	0.50	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

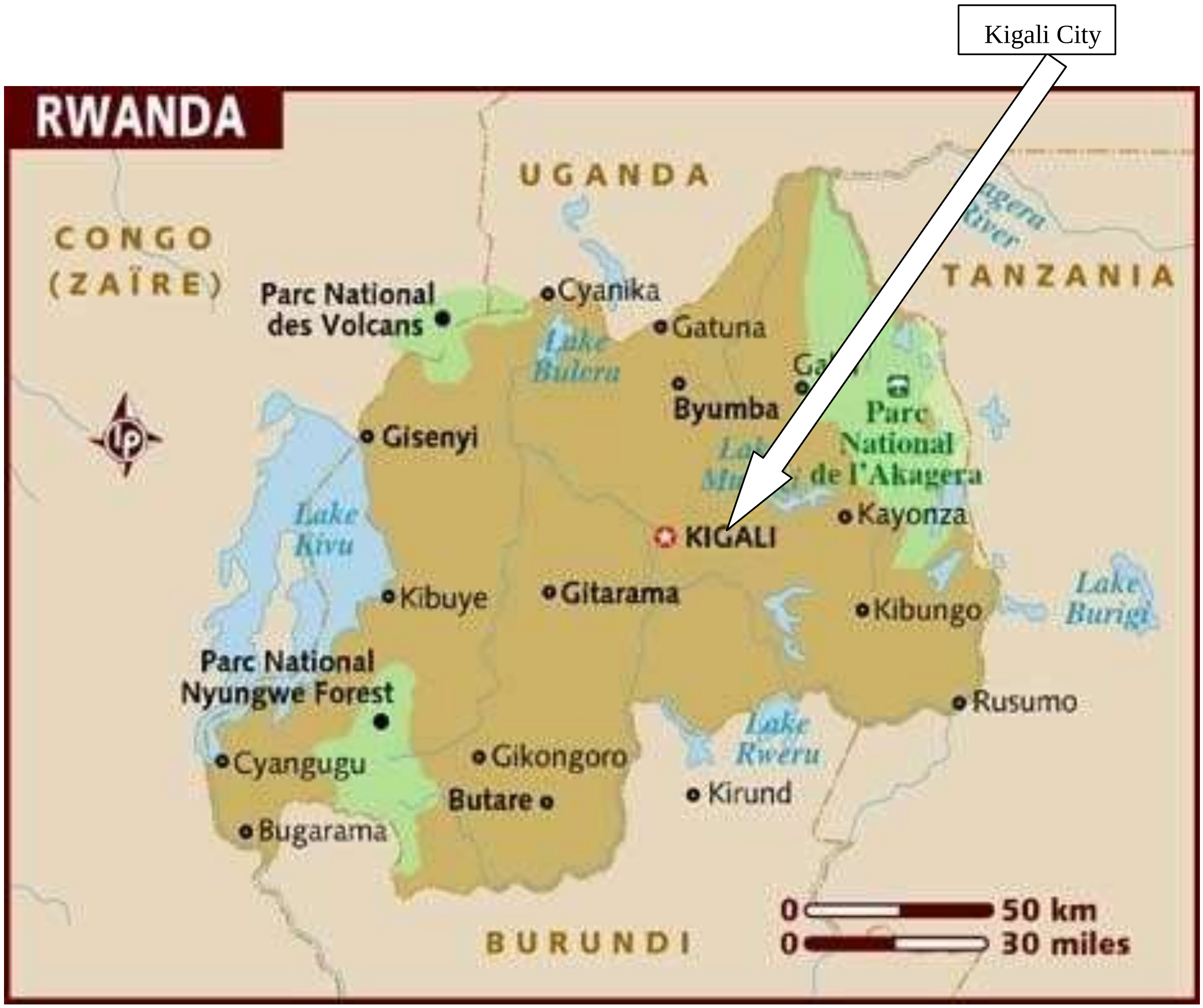
MUHABURA																			
QUANTITYin kg)																			
H6				H7				H8				H9				H10			
W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
1.50	0.50	0.50	0.00	0.00	0.50	0.50	1.00	0.50	1.50	2.00	2.50	9.00	6.00	0.00	0.00	8.00	7.00	9.00	6.00
4.00	0.50	0.00	0.00	3.00	0.50	0.00	2.00	0.00	0.50	3.00	1.50	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
1.00	0.50	1.00	0.00	3.50	0.00	3.00	0.50	0.50	3.00	1.00	0.50	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	1.00	5.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	0.00	0.50	0.30	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.00	7.50	8.00	5.00	5.00	25.00	0.00	0.00	27.00	0.00	1.00	1.00	7.00	8.00	12.00	15.00	0.00	0.00	0.00	0.00
3.00	0.00	0.00	0.00	0.00	0.00	5.00	1.50	0.00	2.00	0.00	0.00	1.00	2.00	0.00	0.00	2.00	3.00	2.00	4.00

7.4 Laboratory work

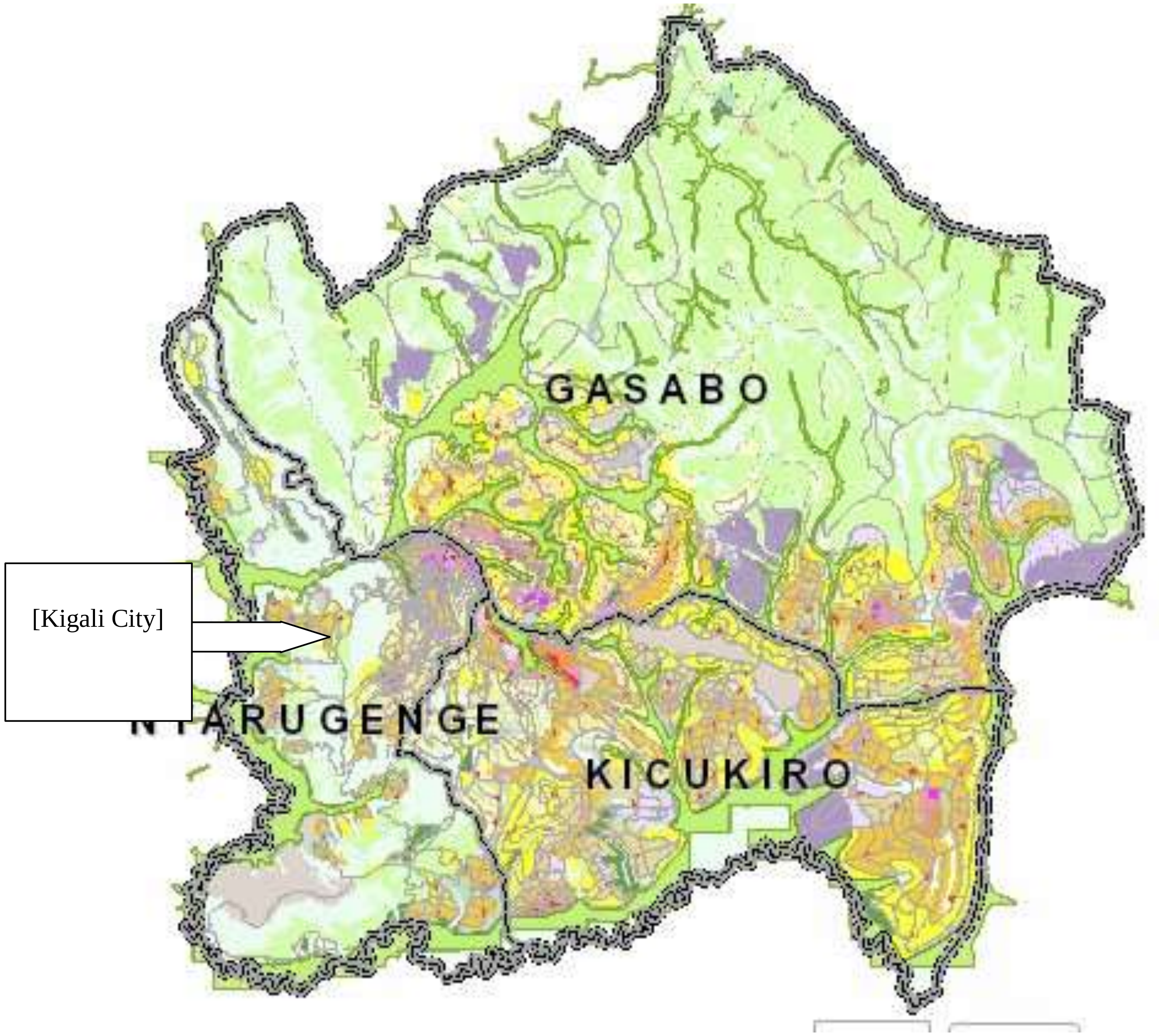
7.5 Field work investigations

Nduba Dumpsite

7.6 Field work localization

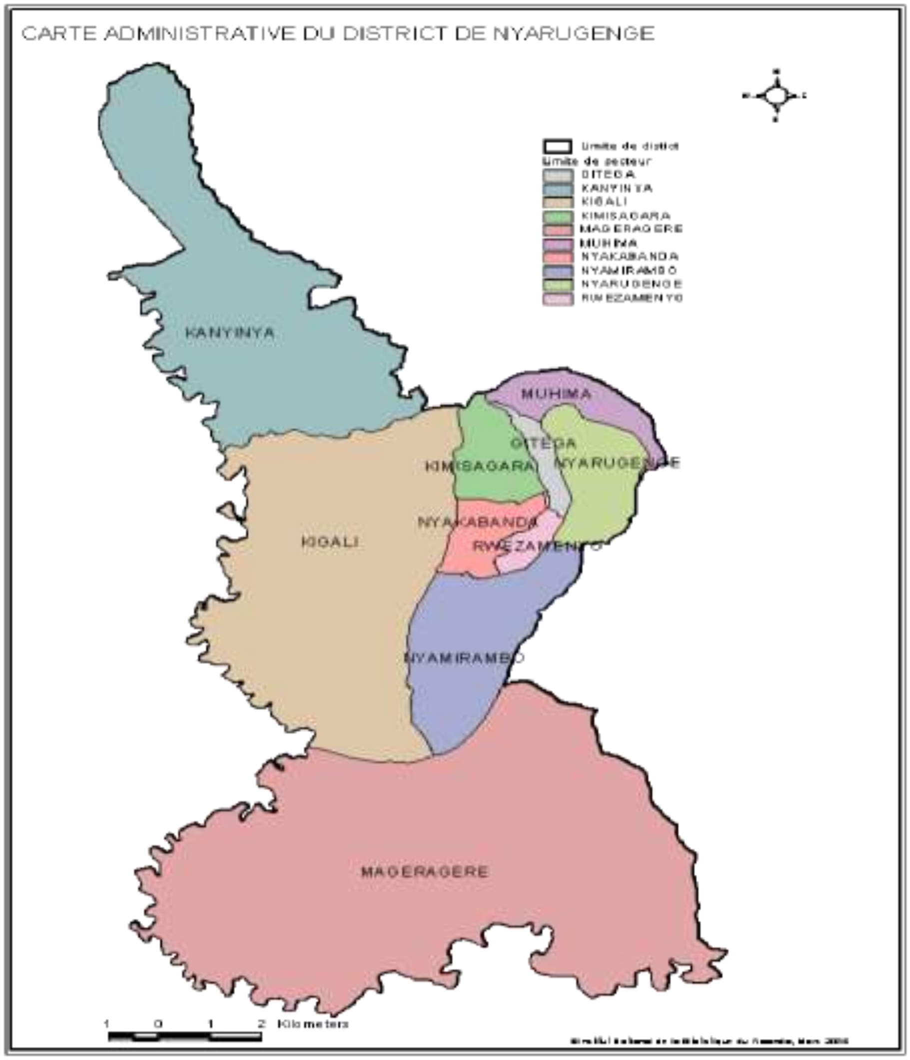


Map of Rwanda



[Kigali City]
GASABO
NYARUGENGE
KICUKIRO

Map of Kigali City Rwanda



Map of Nyarugenge District Rwanda